4. Railway Facilities

4.1 Civil Structures (Railway, Stations)

4.1.1 Railway

This includes basic conditions related to the civil structures such as topographical, geological and soil, seismic, intersections such as existing railway lines, roads, rivers, construction, as well as surrounding environmental conditions. In addition, economic efficiency, workability, construction time, operation and maintenance after the commencement of operations shall be considered. In particular, economic efficiency will be well considered when selecting the civil structures for the HSR system in Vietnam.

The HSR civil structures include earthworks such as embankments and cuts, viaducts, bridges, box culverts, tunnels and station structures. In order to minimize construction costs, for the most part, earth structures are selected in open sections. Viaducts are applied to the areas where earth structure does not much the surrounding environment with high population density, many buildings, roads, and railways. Viaducts are also applied to the areas where the residual settlement of the embankment is expected to be largely due to the weak ground. The points to note for each structure type are shown below.

(1) Earthwork (Embankments and Cuts)

Various aspects, such as collapsing caused by settlement and rainfall, mud-pumping and maintenance, etc., have to be considered when designing and constructing earth structures.

In recent years in Japan, new materials and new construction methods such as layer thickness adjustment materials, reinforcement materials, drainage blankets, slope protection work, and roadbed reinforcement are developed. In addition, the performance-based design methods have made it possible to construct earthworks with the same durability, safety, usability, and recoverability characteristics as concrete structures. It is preferable to adopt soil structure as much as possible for the following reasons:

a) Embankment construction costs are relatively low compared to viaducts.
b) Relatively good-quality embankment materials can easily be obtained in Vietnam. It is also possible to recycle material and use good quality tunnel muck and soil from cuts for embankments.

Construction of very high embankments tends to cause problems for the surrounding environment as they ruin the landscape and require more land. Considering the above, the maximum embankment height construction for Vietnam should be about 9 m on typical sections, and viaducts should be constructed if the height exceeds 9 m, because 9 m high embankments require approximately four times more land than viaducts. Embankment structures divide urban areas and also increase the costs and time required for land acquisition, which in turn can delay construction. This concept matches to the Railway Structure Design Standard for Earthwork edited by RTRI (Railway Technical Research Institute) in Japan.

The formation level of HSR embankments require at least a 1 m clearance on the outside of the wind pressure side for a maintenance walkway, and to prevent the top of the slope from collapsing. About 1 m shall also be provided for a maintenance walkway at the toe of the slope.

Depending on the soil quality, the slope gradient of embankments and cuts shall, in general, be about 1:1.5 to 1.8 and 1:1.5, respectively. If necessary, a 1.5 m wide berm shall be provided for high slopes. The standard height in installing berms to high slopes is over 6.0 m, according to the

Railway Structure Design Standard for Earthwork (RTRI, 2013). Berms effectively prevent slope erosion by reducing the flow speed and amount of surface water during rainfall, and they can also be used as walkways for slope maintenance. In case that the land where cut structures are applied is difficult, depending on the soil quality, the slope gradient of the retaining wall shall, in general, be about 1:0.35 with an earth retaining wall structure.

The use of reinforcement materials is effective in improving the earthquake and rain resistance of embankments. Embankment reinforcement materials are different from thickness adjustment materials and are not used for auxiliary surface compaction; they aid to increase tensile strength and prevent rotational slip.

The establishment of the slope protection works is effective for the prevention of slope erosion of embankments and cuts, rainwater infiltration, surface slip, and protection of the environment. The types and performance of the main slope protection works used for embankments and cuts are described in Table 4.1 and Table 4.2.

Table 4.1: Types and Performances of Slope-Protection Works for Embankments

Type	Parformance				
	Seepage control	Prevention against surface layer erosion	Prevention against surface layer slip	Prevention of soil erosion caused by spring water	Environmental protection by greening
Concrete-block pitching	◎	◎	○	○	-
Anti-weed sheets	◎	◎	-	-	○
Lattice frame work	-	◎	◎	◎ *1	◎ *2
Rip rap masonry	-	◎	○	○	-
Planting work	-	○	-	-	◎

◎: Excellent performance ○: Good performance -: No effect
*1: Inside protected by cobble stones *2: Inside protected by planting works
Source: Railway Structures Design Standard for Earthwork (Railway Technical Research Institute, 2013)

Table 4.2: Types and Performances of Slope-Protection Works for Cuts

Type	Parformance					
	Seepage control	Prevention against surface layer erosion	Prevention against wethering	Prevention against surface layer collapse and peeling	Prevention of soil erosion caused by spring water	Environmental protection by greening
Concrete-block pitching	◎	◎	◎	-	○	-
Pre-cast concrete lattice framework	-	○	○	○	◎ *1	◎ *2
Cast-in-place concrete lattice framework	-	◎	○	◎	◎ *1	◎ *2
Spray framework	-	◎	○	◎	◎ *1	◎ *2
Concrete protection work	◎	◎	◎	◎	○	-
Waterproof anti-weed sheets	◎	◎	◎	-	-	○
Mortar spraying work	◎	◎	◎	○	○	-
Concrete spraying work	◎	◎	◎	○	○	-
Planting work	-	○	-	-	-	◎

◎: Excellent performance ○: Good performance -: No effect
*1: Inside protected by cobble stones *2: Inside protected by planting works
Source: Railway Structures Design Standard for Earthwork (Railway Technical Research Institute, 2013)

When the supporting ground is soft, pre-loading and vertical drains can be used as countermeasures against soft ground. If soil improvement is uneconomical due to the depth required, viaducts supported by foundation piles are recommended instead of embankment structures. Since there are many soil improvement methods, it is necessary to pay attention to economic efficiency as well as local soil and environmental conditions in order to select an appropriate method. Typical soil improvement methods are listed below.

i) Surface Treatment Method
Shallow soft layers up to a depth of about 2-3 m can be treated. Those are replacement, surface mixing with good soil, and laying sand to drain the groundwater. In Vietnam, the replacement method is recommended due to its economic efficiency and workability.

ii) Accelerated Consolidation Method
The accelerated consolidation method is used to compact cohesive soil consolidation and drainage with loading and drain material. However, it is necessary to observe any adverse effects on nearby structures. If the construction period is long enough, the pre-loading method is more economical. The sand drain method is recommended if the location of the consolidation layer is thick and rapid consolidation is required.

iii) Compaction and Tamping Method
The compaction and tamping method includes the sand compaction pile and the vibro-flotation methods. These methods are used to press sand into the ground by vibration and impact loading. However, vibration and noise pollution are problems associated with this method.

iv) Soil Solidification Method
Soil solidification methods include the deep mixing and the lime-pile methods. Soil solidification involves treating deep soil layers by hardening existing soil with solidifying materials. Vibration and noise generally do not cause a problem with this method. If construction cost is high and the area to be treated is large, the cost of this method should be compared to viaduct construction with pile foundations.

v) Pile-net Method
If the depth of the soft layer is about 3-10 m, the construction cost of this method is cheaper than that of the soil improvement methods, but some vibration and noise occur during pile driving.

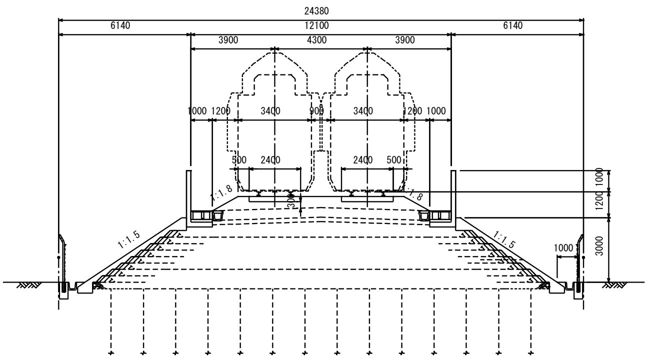
For this project, taking into account past construction experience with soil improvements in Vietnam and economic efficiency, the accelerated consolidation method shall be applied as a countermeasure against soft ground areas.

Roadbeds for ballast track on embankments and cuttings shall be strengthened by using mechanically stabilized crushed stone for the lower layer and asphalt for the upper layers of the roadbed, as this prevents rainwater penetration and improves abrasion resistance. Thus, the stability and durability of the roadbed are improved, and mud pumping caused by train loading can also be prevented.

Proper drainage of the embankment is also important, and placing drainage blankets under the toe of the slope is effective in preventing both an increase in pore water pressure inside the embankment and the collapse of the structure.

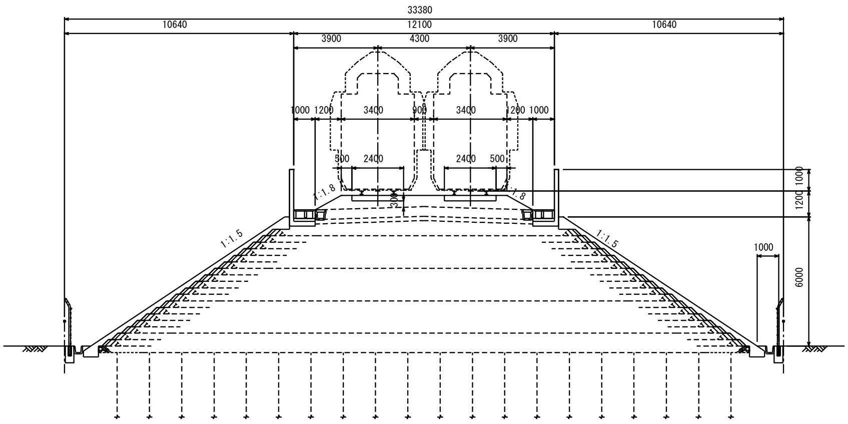
In Vietnam, there are lots of pastured cattle and wild animals. Therefore, to ensure the safety and stability of HSR operations and to prevent animals intruding into railway premises, fences need to be installed in the locations where embankments and cuts are constructed.

Figure 4.1 to Figure 4.3 show typical embankments, and Figure 4.4 to Figure 4.9 show typical cuts of different heights.



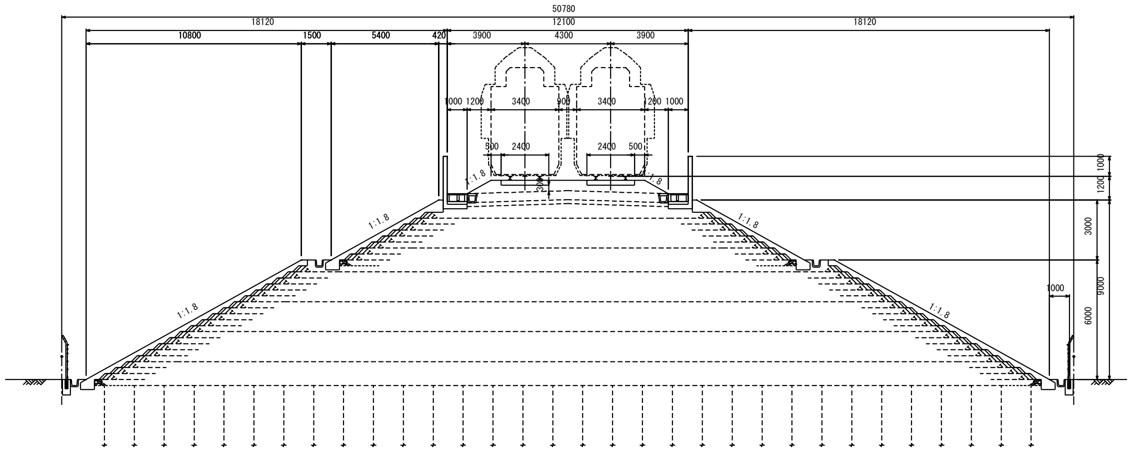
Source: JICA Study Team

Figure 4.1: Typical Embankments Type 1



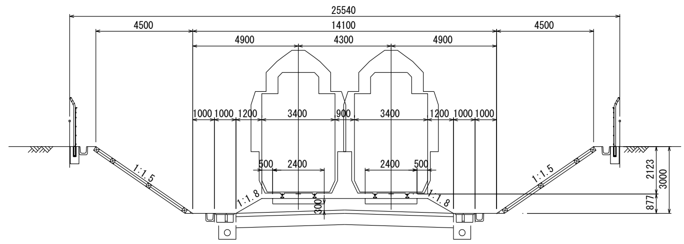
Source: JICA Study Team

Figure 4.2: Typical Embankments Type 2



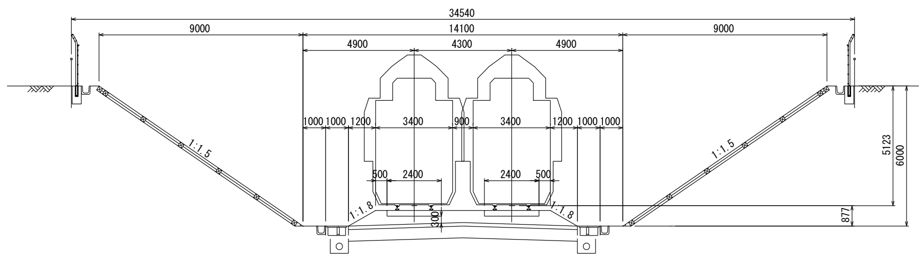
Source: JICA Study Team

Figure 4.3: Typical Embankments Type 3



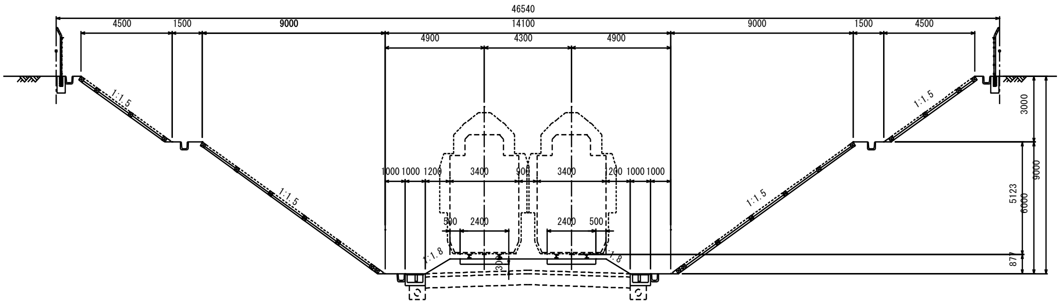
Source: JICA Study Team

Figure 4.4: Typical Cuts Type 1



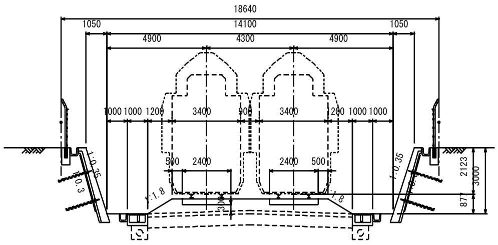
Source: JICA Study Team

Figure 4.5: Typical Cuts Type 2



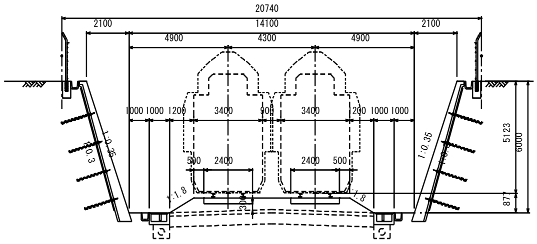
Source: JICA Study Team

Figure 4.6: Typical Cuts Type 3



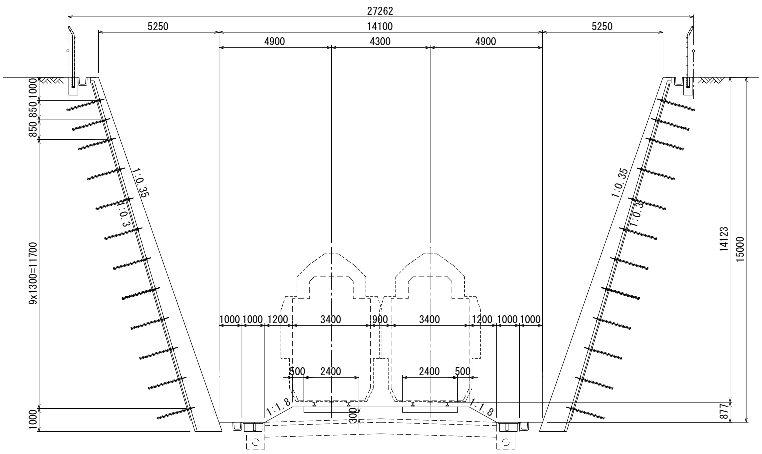
Source: JICA Study Team

Figure 4.7: Typical Cuts Type 4



Source: JICA Study Team

Figure 4.8: Typical Cuts Type 5



Source: JICA Study Team

Figure 4.9: Typical Cuts Type 6

(2) Viaducts and Bridges

In order to ensure the safety and stability of HSR operations, all existing railway lines and roads require grade-separated crossings. These shall be constructed as viaducts if embankments cannot be used due to excessive height or soft ground. In some locations, however, the independent grade separation of roads might have to be considered instead.

PC T-girders and PC box girders shall typically be used for viaducts, over-bridges and pedestrian overpasses in urban areas for the following reasons.

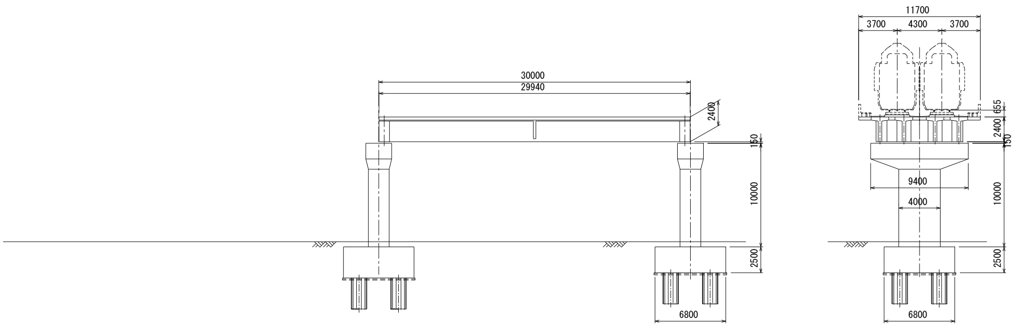
a) Although Japanese style rigid-frame viaducts are economical and have the lowest material costs of all viaduct structures, their complicated bar arrangement can pose problems during construction supervision in Vietnam. On the other hand, PC girders are commonly used in many countries and are fast to construct if identical continuous girders are employed.

b) PC T-girders and PC box girders shall be applied to reduce maintenance costs and increase economic efficiency compared with RC girders construction,

c) The construction cost of girder viaducts is determined by the length of the PC T-girders in relation to the number of spans and piers. Generally, L=30 m PC T-girder viaducts are most economical. In this project, PC T-girders can be adopted for L=30 m and 40 m as typical viaducts and bridges. The longer 40 m PC T-girder viaducts/ bridges will only be applied when 30 m does not match to the intersection conditions of roads, rivers and etc. The girders are usually fabricated at yards near the construction site and erected with cranes. For increased economic efficiency, the formwork can be moved and reused in other locations.

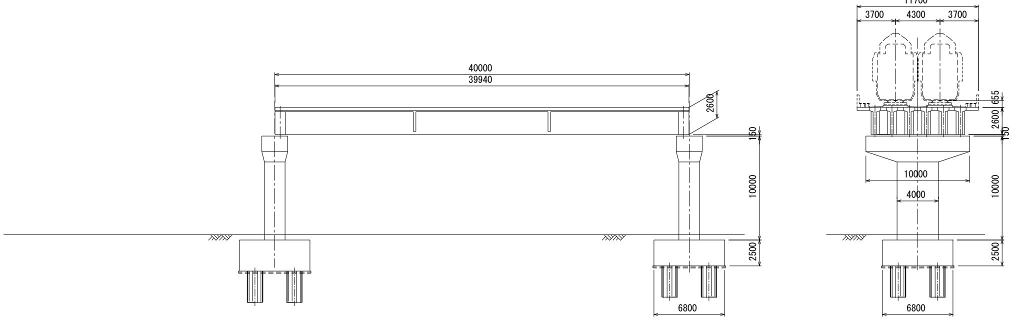
d) PC box girders will be adopted for bridges with L=60 m and are commonly used both overseas and for many Shinkansen bridges in Japan. Although scaffolding and girder falsework is generally used for construction, it is also possible to use the incremental launching and lateral transfer methods.

In this project, the cast-in-place concrete pile foundation is applied as the substructure type. Typical drawings of girder viaducts are shown below in Figure 4.10 to Figure 4.12.



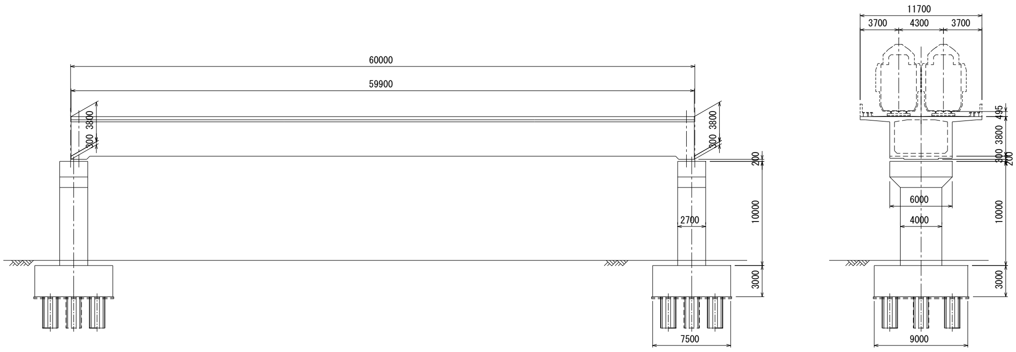
Source: JICA Study Team

Figure 4.10: Typical Viaducts Type 1



Source: JICA Study Team

Figure 4.11: Typical Viaducts Type 2



Source: JICA Study Team

Figure 4.12: Typical Viaducts Type 3

As running safety and riding comfort are very important for HSR rolling stock, strict limits have to be set for girder deflection, unevenness and angular rotation of the track surface, and differential displacement. These limits also have to be considered when selecting the girder structure type.

Table 4.3: Design Limit Values for Girder Deflection Based on Running Safety under Normal Conditions

Number of spans	Maximum speed (km/h)	Girder or member span length Lb (m)									
		10	20	30	40	50	60	70	80	90	More than 100
Single	260	Lb/700									
	300	Lb/900									
	360	Lb/1100									
Multiple	260	Lb/1200						Lb/1400			
	300	Lb/1500						Lb/1700			
	360	Lb/1900						Lb/2000			

Source: Railway Structures Design Standard for Displacement Limit (Railway Technical Research Institute, 2006)

Table 4.4: Design Limit Values of Vertical Unevenness of Track Surface Based on Running Safety under Normal Conditions

Maximum speed (km/h)	Single span (mm)	Multiple span (mm)
260	2.0	3.0
300	1.5	2.5
360	1.0	2.0

Source: Railway Structures Design Standard for Displacement Limit (Railway Technical Research Institute, 2006)

Table 4.5: Design Limit Values for Angular Rotation of Track Surface Based on Running Safety under Normal Conditions

Maximum speed (km/h)	Vertical dilection θ L(・1/1000)		Horizontal dilection θ L (・1/1000)	
	Parallel displacement	Folding	Parallel displacement	Folding
210	4.0	4.0	2.0	2.0
260	3.0	3.0	1.5	2.0
300	2.5	2.5	1.0	1.0
360	2.0	2.0	1.0	1.0

Source: Railway Structures Design Standard for Displacement Limit (Railway Technical Research Institute, 2006)

Table 4.6: Limit Values for Differential Displacement of Track Surface during Earthquakes

Direction	Maximum speed (km/h)	Angular rotation θ L (・1/1000)			Unevenness (mm)
		Parallel Displacement		Folding	
		Lb=10m	Lb=30m		
Horizontal	210	5.5	3.5	4.0	10
	260	5.0	3.0	3.5	8
	300	4.5	2.5	3.0	7
	360	4.0	2.0	2.0	6

Lb: Girder or member span length

Source: Railway Structures Design Standard for Displacement Limit (Railway Technical Research Institute, 2006)

(3) Large Bridges

Large bridges can be classified into concrete bridges, metal truss bridges, and composite girder bridges. Furthermore, concrete bridges can be divided into continuous rigid frame girders or continuous girders. It is important to consider the economic aspects and workability of large bridges that cross rivers, railways, and highways.

Continuous rigid frame girders shall typically be used for large bridges for the following reasons.

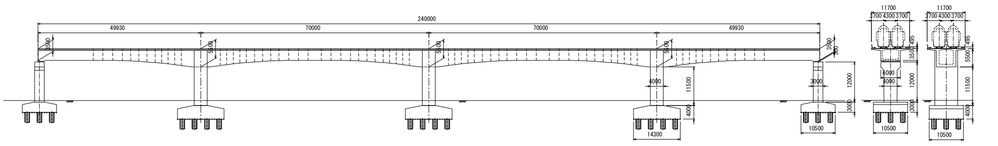
a) In order to ensure running safety and riding comfort for HSR rolling stock, strict limits have to be set for girder deflection, unevenness and angular rotation of the track surface, and differential displacement. The concrete bridge is more economical than other types of bridges to fulfill the limit requirements set for deflection and unevenness.

b) To increase seismicity and to reduce construction and maintenance costs, continuous rigid frame girders are adopted for large bridges. When adopting continuous rigid frame girders, there is no necessity of installing bearings systems such as rubber bearing and stopper at column head parts.

The structural types and spans of large bridges are normally decided upon consultations with the river administrator and road administrator. Therefore, they should be determined at later stages, and types and spans may vary at each location.

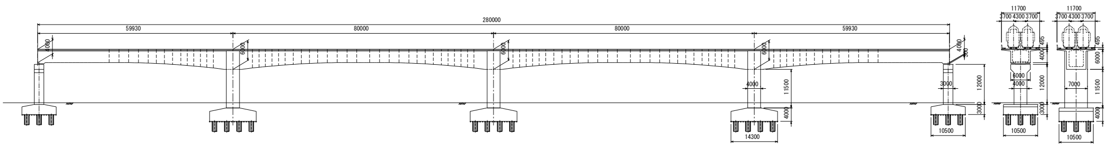
Here, two types of large bridges are proposed: 70 m@2 + 50 m@2 = 240 m, 80 m@2 + 60 m@2 = 280 m.

Typical drawings of large bridges are shown in Figure 4.13 and Figure 4.14.



Source: JICA Study Team

Figure 4.13: Typical Large Bridges Type 1



Source: JICA Study Team

Figure 4.14: Typical Large Bridges Type 2

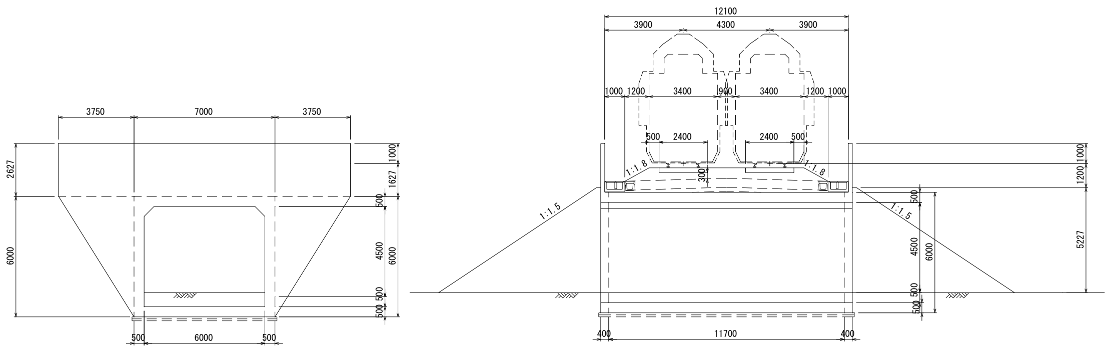
(4) Box Culverts

Embankment construction works may cut off roads and waterways and cause water to dam up during rainfall. Generally, medium and large roads that cross embankments require bridge abutments, but box-culverts are more economical for rural and narrow roads.

The following items shall be considered when box culverts are designed.

a) Setting inner section of road
b) Countermeasures to prevent settlement of joint sections between embankment and box culvert (installation of approach block)
c) Setting groundwater level height considering existing deformation

Typical drawings of box culverts are shown in Figure 4.15.

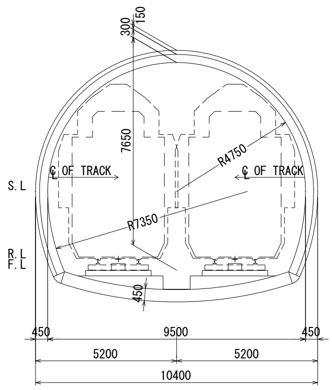


Source: JICA Study Team

Figure 4.15: Typical Box Culverts

(5) Tunnels

Tunnels shall generally be constructed with the NATM method and have the same as the double-track Shinkansen lines in Japan. Typical drawings of tunnels are shown in Figure 4.16.



Source: JICA Study Team

Figure 4.16: Typical Tunnels

The typical tunnel excavating method, method of tunnel face division, tunnel entrance type, and auxiliary construction method are shown as follows;

a) Tunnel excavating method

Drill and blast, the mechanical excavation and tunnel boring machine are typical methods for tunnel excavation, as explained in below table.

Table 4.7: Tunnel Excavating Method

	Blasting method	Mechanical excavation	
		Universal and/or partial face machines	Shield Method
Abstract	• Blasting.	• Tunnel face and sidewall is excavated mechanically using universal and/or partial face machines.	• Excavate manually or mechanically in the shield.
Equipment & Materials	• Dynamite, ANFO, explosives, etc. • Electric detonator and Non-electric detonator etc.	• Roadheader, breaker, boom header, particular types of excavators are available to use for excavation.	• Shield. • Excavator. • Segment elector.
Feasible geology	• Hard rocks to medium-hard rocks	• Hard rocks to medium-hard rocks	• Medium-hard rocks to soft ground
Advantage	• Applicable to tunnels except for soft grounds. • According to natural ground properties, the support system can be introduced and adjusted.	• Compared to blasting, the excavating range can be reduced. • Excavating machines can be applied depending on geological condition.	• Higher safety against collapse. • Minimize the ground surface settlement on the tunnel. • Almost all works and activities shall be done under the shield. • Few vibration and noise problems. • Advantageous in an urban area.

	Blasting method	Mechanical excavation	
		Universal and/or partial face machines	**Shield Method**
Disadvantage	• Tunnel advancement speed is highly dependent on the skill of the workers. • Overbreak possibility is larger than the other methods. • Generation of noise, dust, vibration problem.	• High-level noise, dust, and vibration, but not so much as blasting. • Excavation speed depends on the skill of the operator.	• Not flexible with variations in geology.

Source: JICA Study Team

b) Tunnel excavation method

Table 4.8 shows the excavation method and applicable conditions.

Table 4.8: Division of Tunnel Heading Section

Excavation method		Applicable ground condition	Advantages	Disadvantages
Full face excavation		• Small-section tunnel. • Very stable ground for large section tunnels (A>60 m^2). • Relatively stable ground for medium section tunnels (A>30 m^2). • When ground condition gets worse, the excavating procedure is forced to change.	• Labor-saving by mechanization. • Construction management, including safety control, is easy because of the single face excavation.	• Sometimes it can be difficult to excavate the entire tunnel length only by the full-face, and an alternative excavation would be required. • Unstable rocks may fall from tunnel crown, requiring additional safety measures to prevent small collapses.
Full face excavation with auxiliary bench cut		• Relatively stable grounds, but difficult for the full-face excavation. • In case the full face excavation becomes difficult because of geological change. • Relatively good grounds even mixed with bad rocks.	• Labor-saving by mechanization. • Construction management, including safety control, is easy due to the single face excavation.	• In case tunnel face becomes unstable, an alternative excavation method would be required. • Change of the excavation method would take time and incur costs.
Bench cut excavation	Long bench cut method	• Relatively stable grounds, but difficult for full-face excavation. • The ring cut method shall be used when the face becomes unstable.	• Labor-saving is possible when dividing the tunnel face into upper and lower parts and excavate alternately.	• The construction period is long.

Excavation method		Applicable ground condition	Advantages	Disadvantages
	Short bench cut method	• Ring cut method shall be applied when the tunnel face becomes unstable.	• Adjustable to the sudden changes in ground conditions.	• Parallel excavation of top heading and bench shall be unfavorable due to the difficult to control cycle time. • Access road between upper half part and lower half part is difficult to be installed, countermeasure to dispose soils is necessary.
	Mini bench cut method	• Applicable to unstable ground. • Possible to stabilize tunnel face by short bench but method. • In cases when closing is needed quickly due to soft ground and/or difficult ground such as swelling.	• Invert is easy to close.	• Large and usual equipment would be difficult to use due to the narrow space. • A construction base needs to be installed for construction of the upper half portion.
	Multiple bench cut method	• Available to use with fairly good ground and large sections.	• Easy to stabilize the face.	• The deformation of the tunnel needs to be large due to the delay of support installation. • Large and usual equipment would be difficult to use due to the limited bench space. • Cycle time is highly affected by the excavation and mucking system.
	Center diaphragm method	• Usually applied to shallow overburden with soft ground to minimize ground settlement. • Relatively large section area.	• Stability of the tunnel face shall be obtained by division of full-face. • The center diaphragm is effective to prevent ground settlement.	• Deformation of the tunnel should be measured carefully during removal of the center diaphragm. • Additional support members would be required to stabilize the tunnel face.
Drift and heading method	Side-drift method with the sidewall (Hard Rock)	• It is applied to large sections of tunnel with good rock conditions. • The ground conditions such as geology, water seepage should be inspected before and during tunnel construction.	• Relatively massive concrete wall for side drifts improves the bearing capacity. • Effective against the unsymmetrical load acting from the inclines of ground surface.	• Excavation equipment is limited by the section of side drill. • The construction schedule will be longer than the bench cut etc.

Excavation method		Applicable ground condition	Advantages	Disadvantages
	Side-drift method without sidewall (Soft Rock)	• Usually applied to the soft grounds and/or difficult grounds such as swelling, squeezing. • It is applied to tunnel portal excavation under the unfavorable ground conditions.	• Effective to protect ground settlement and large deformation of the tunnel. • The section of drift shall be changed to fit the ground conditions.	• Excavation equipment is limited by the section of the side drift. • The construction schedule will be longer than the bench cut etc.
	Top heading and center drift, bottom drift advance	• Difficult geological conditions such as soft grounds, some amount of water seepage.	• Effective to stabilize the face and installation of primary support. • Available to predict ground conditions in front of tunnel face. • Possible to dewater the existing sections in front of tunnel face.	• Large and generalized equipment is difficult to apply as the section of drift is not enough. • Some special equipment or manpower for the excavation is required. • These methods would increase excavation costs.
	Top heading using tunnel boring machine (TBM)	• It is applied to the large section tunnels with good rock conditions. • Ground conditions such as geology, water seepage, etc., should be inspected before and during tunnel construction.	• Available to predict ground conditions in front of tunnel face. • Effective to stabilize the face during tunnel widening. • Very effective to shorten the construction period.	• Difficult to change the excavation method if ground conditions become worse.

Source: Previous Study (JICA, 2013)

c) Tunnel Entrance Type

Study of the installing location and structure type of tunnel entrance should take into account the following factors;

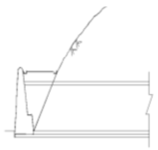
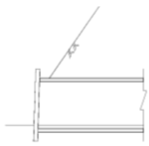
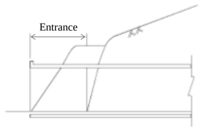
i) Topology, the geology of the portal area
ii) Overburden thickness around the tunnel portal
iii) Environmental conditions

The collapse of the tunnel crown/arch may occur when the tension is stressed at the tunnel crown, and the magnitude of redistributed stress exceeds the tensile strength of the surrounding rocks. The result of numerical analysis of the tunnel indicates that the tension zone would gradually disappear when the overburden thickness increases.

A desirable thickness of overburden at the tunnel portal is commonly considered at more than 1.5D to 2.0D (D: tunnel diameter) in order to have a “Ground Arch Effect” to reduce the support members. However, the location of the tunnel portal should be selected, considering the topography and geology of each tunnel.

Common types of the entrance structures for railway tunnels are shown in Table 4.9.

Table 4.9: Division of Tunnel Heading Section

	Retaining wall type	Wall type	Limb type
Scheme			
Applicability	• Moderately to steeply inclined slopes where a retaining wall for slope protection is required. • A large amount of rockfall is anticipated. • This type is not popular at the present stage.	• Moderately to steeply inclined slopes where cut is needed for tunnel portal construction. • In the case of a tunnel, the route is intersecting with the slope at a shallow angle, protecting countermeasures are required against the uneven load.	• It is applied to moderately inclined slopes. • A bank for countermeasure of slope collapse is constructed. • For slope work around the tunnel, the entrance has no particular difficulties.
Remarks	• Installation of pillars or improvement of the foundation is required in bad geological conditions.	• The entrance wall should be combined with the tunnel lining structure.	• The length of tunnel becomes long. • Countermeasures should be considered.

Source: Previous Study (JICA, 2013)

d) Tunnel Auxiliary Method

The tunnel auxiliary method is classified into fore-pile/pole method, reinforcement method for tunnel face/side part, ground reinforcement method, and spring water countermeasure. The application of the fore-pile/pole method is recommended, as this method is the most advantageous economically and from the construction experiences in Vietnam compared with other methods.

The fore-pile/pole method can be classified into several methods; ordinary methods are described in Table 4.10.

Table 4.10: Tunnel Auxiliary Method

	Fore-poling with filling material method	Fore-poling with grouting material method	Fore-piling with grouting material method
Abstract	• In order to ensure stability of the tunnel crown, anchor bars less than 5 m in length are installed obliquely forward with a 60 cm pitch from the face part of tunnel crown.	• In order to ensure stability of the tunnel crown, anchor bars less than 5 m in length are installed obliquely forward with a 60 cm pitch from the face part of tunnel crown, and grouting materials such as urethane are filled into the locations where the anchor bars are installed.	• In order to ensure stability of the tunnel crown, anchor piles between 5 m to 12 m in length are installed obliquely forward with a 45 cm pitch from the face part of tunnel crown, and grouting materials that are cement-based or silica resin-based are filled into the locations where the anchor piles are installed.

	Fore-poling with filling material method	Fore-poling with grouting material method	Fore-piling with grouting material method
Advantage	• Ordinary machines can be applied. • Construction cost is economical.	• Ordinary machines can be applied. • It can easily adapt to changes in ground conditions.	• It can easily adapt to changes in ground conditions. • Since the reinforcing range is long, it is possible to separate the excavation work and auxiliary work.
Disadvantage	• The stability depends on ground conditions.	• Since the reinforcing range is short, stability of the area ahead of the face of the tunnel is not ensured.	• The fore-poling method enables an easier construction than the fore-piling method does.

Source: JICA Study Team

e) Tunnel Buffer Construction

When the train enters the tunnel at high speed, the air in the tunnel is compressed, and a plosive sound is created at the exit on the opposite side. In order to reduce this sound, it is necessary to install a tunnel buffer at the entrance. There are two types of tunnel buffer constructions, the metal type and concrete type. Generally, the necessary cross-sectional area of tunnel buffer construction should be about 1.4 times the cross-sectional area of tunnel, which should be incorporated in the design of the length and opening of the tunnel buffer.

(6) Station Structures

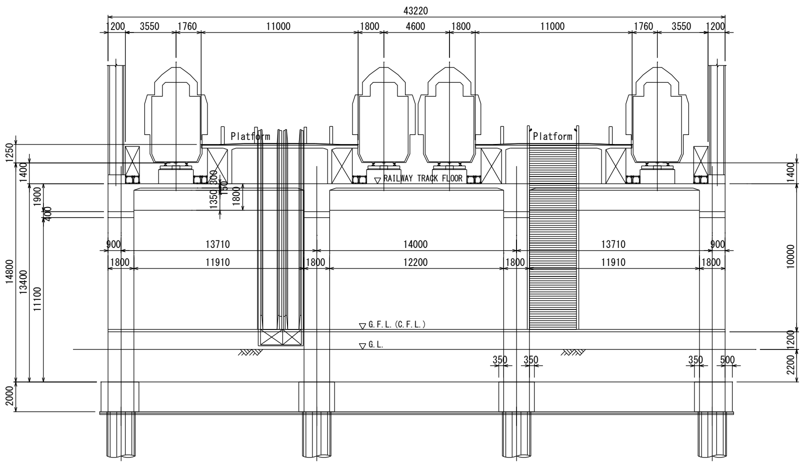
Station structures can be classified into elevated stations, ground-level stations, and underground stations. Stations that are located in grade-separated sections can be constructed directly above railways or roads, or the lower levels can be used for the concourse or commercial facilities. Moreover, depending on the profile conditions, stations can also be located at grade or underground.

Here, four types of stations are proposed: 2-layer structure with 2-island type platforms and 4-lines, 2-layer structure with 2-opposite type platforms and 4-lines, 1-layer structure with 2-island type platforms and 4-lines and 1-layer structure with 2-opposite type platforms and 4-lines.

Stations with two layers basically employ rigid-frame viaduct structures based on the following considerations:

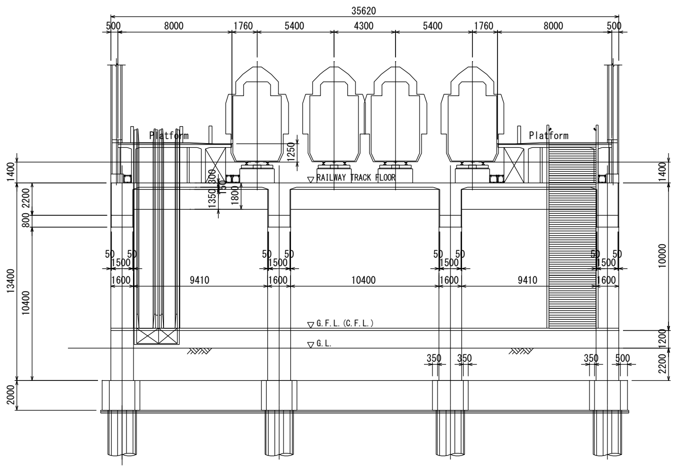
- Since it is necessary to consider space utilization under the viaduct, rigid-frame pier substructures rather than wall-type substructures are recommended, as they allow pier locations to be determined based on the concourse layout.

- Rigid-frame type rather than girder type can provide versatile pier allocations that would not affect the locations of escalators and stairs. Rigid-frame types are easy to deal with during construction of slab opening.



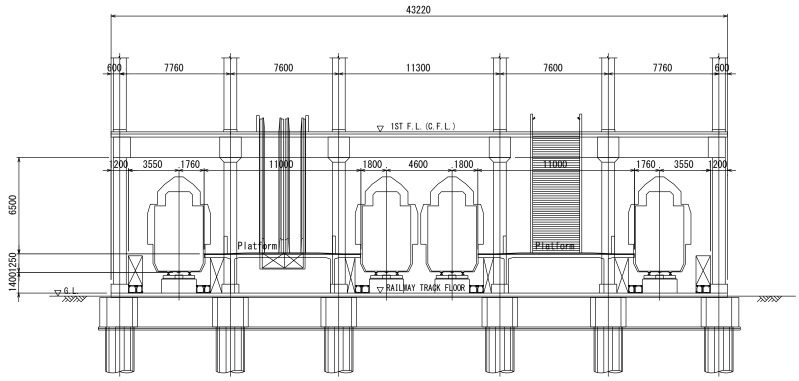
Source: JICA Study Team

Figure 4.17: Typical Stations Type 1



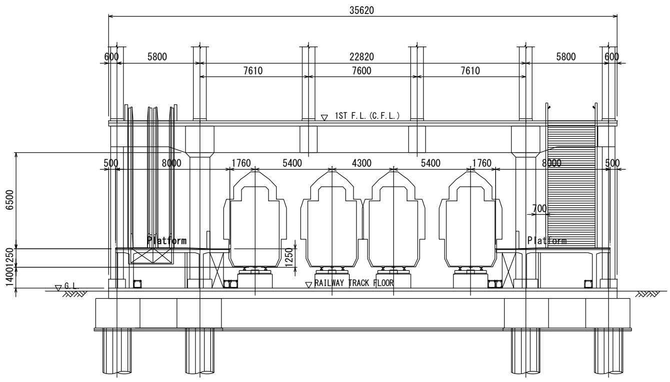
Source: JICA Study Team

Figure 4.18: Typical Stations Type 2



Source: JICA Study Team

Figure 4.19: Typical Stations Type 3



Source: JICA Study Team

Figure 4.20: Typical Stations Type 4

4.1.2 Station and Station Facilities

(1) Basic Concept

The following are major points of consideration for the planning and designing of stations:

- Design
  The design shall relieve the tension that passengers feel when traveling.

- Space
  For the purpose of getting on and off the train, space shall be created where the functions of the station are easy to understand.

- Facility
  Safe and easy-to-use facilities shall be planned in order to cope with earthquakes, adverse weather, fires, etc. as well as to be friendly to the mobility disadvantaged people.

- Comfort
  In addition to functionality, a plan that would provide convenience and a pleasant environment shall be created, such as waiting rooms in the station premises, cafes, and restaurants, souvenir shops, etc.

- Convenience and Profitability
  For the effective usage of HSR facilities, the convenience of passengers and surrounding residents shall be considered. In addition to branch offices of public institutions, facilities such as restaurants, food courts, brand shops, souvenir shops, etc. shall be visually attractive for many people to visit. Further, for the operator, it would be possible to earn profits in addition to the revenue from transportation.

(2) Platform Length

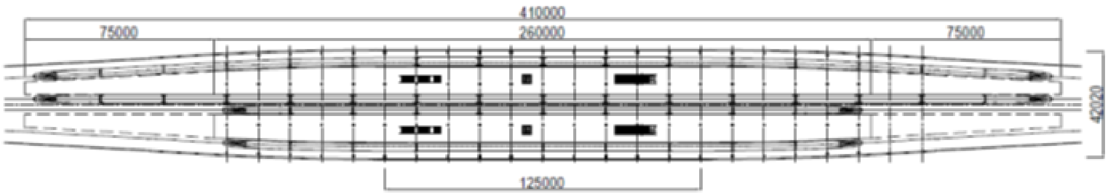
The train size is planned to be standardized with a length of 25.0 m and a width of 3.4 m. The number of cars per train set at the start of operation is planned to be 10 and could be increased up to 16 in the future. The platform is designed with a length of 260 m (spare 5 m + 25 m × 10 cars + spare 5 m), and in the future, the platform is assumed to be expanded by 75 m at both ends for a total length of 410 m (75 m + 260 m + 75 m*).

(3) Safety Fence

For the platform, a safety fence shall be installed to prevent strong wind pressure and falls from the platform when the train passes at high speed of over 260 km/h. The safety fence shall secure a distance of 2 m from the edge of the platform when the train passes at high speed. The safety fence of 2 m at full speed has been assumed.

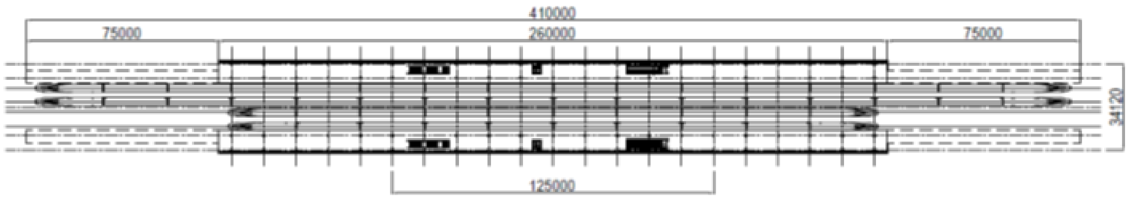
(4) Station Area

The station area is based on the station styles, which is determined by the estimated passenger volume. The station styles include the number of platforms and railway lines planned within a minimum radius of 1,200 m from train operation. The station types are shown in the following figures.



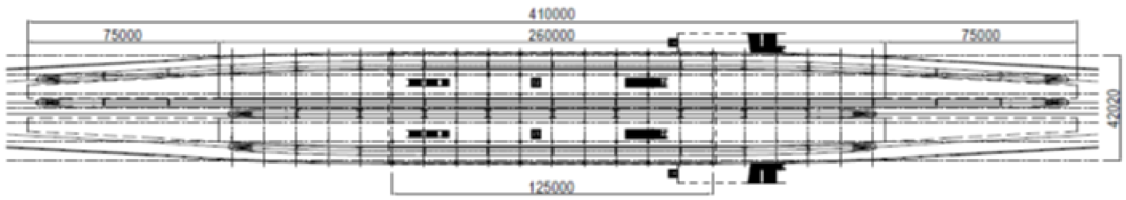
Source: JICA Study Team

Figure 4.21: Station Type 1: 2 Island Platforms with 4 Lines, Elevated



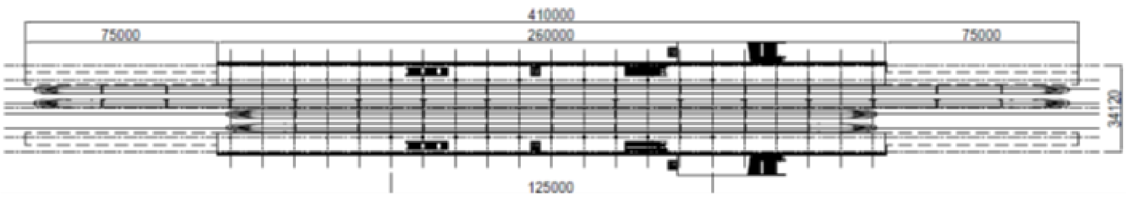
Source: JICA Study Team

Figure 4.22: Station Type 2: 2 Side Platforms with 4 Lines, Elevated



Source: JICA Study Team

Figure 4.23: Station Type 3: 2 Island Platforms with 4 Lines, Ground



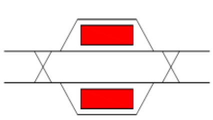
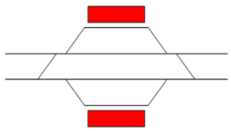
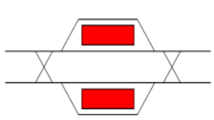
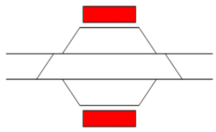
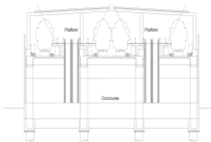
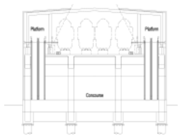
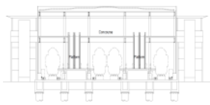
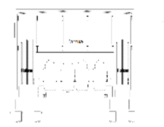
Source: JICA Study Team

Figure 4.24: Station Type 4: 2 Side Platforms with 4 Lines, Ground

(5) Summary of Station Elements

The outline of the station elements is shown in the following figure.

Table 4.11: Outline of Station Elements

Station Type	Type 1	Type 2	Type 3	Type 4
Track Layout				
Station Section				
Platform Type	Elevated	Elevated	Ground	Ground
Platform Type	Island Platform	Side Platform	Island Platform	Side Platform
Platform Length (m)	260	260	260	260
Platform Width (m)	11+11	8+8	11+11	8+8
Station Area (m^2)	16,300	13,200	17,000	13,900
Platform Floor Area (m^2)	11,000	8,900	11,000	8,900
Concourse Floor Area (m^2)	5,300	4,300	6,000	5,000
Place of Gate	1	1	1	1
Elevator (Paid Area/ Public Area)	2/0	2/2	2/0	2/2
Escalator (Paid Area/ Public Area)	4/0	4/2	4/0	4/2
Staircase (Paid Area/ Public Area)	2/0	2/2	2/0	2/2
Toilet (M/F/Disable)	1/1/1	1/1/1	1/1/1	1/1/1

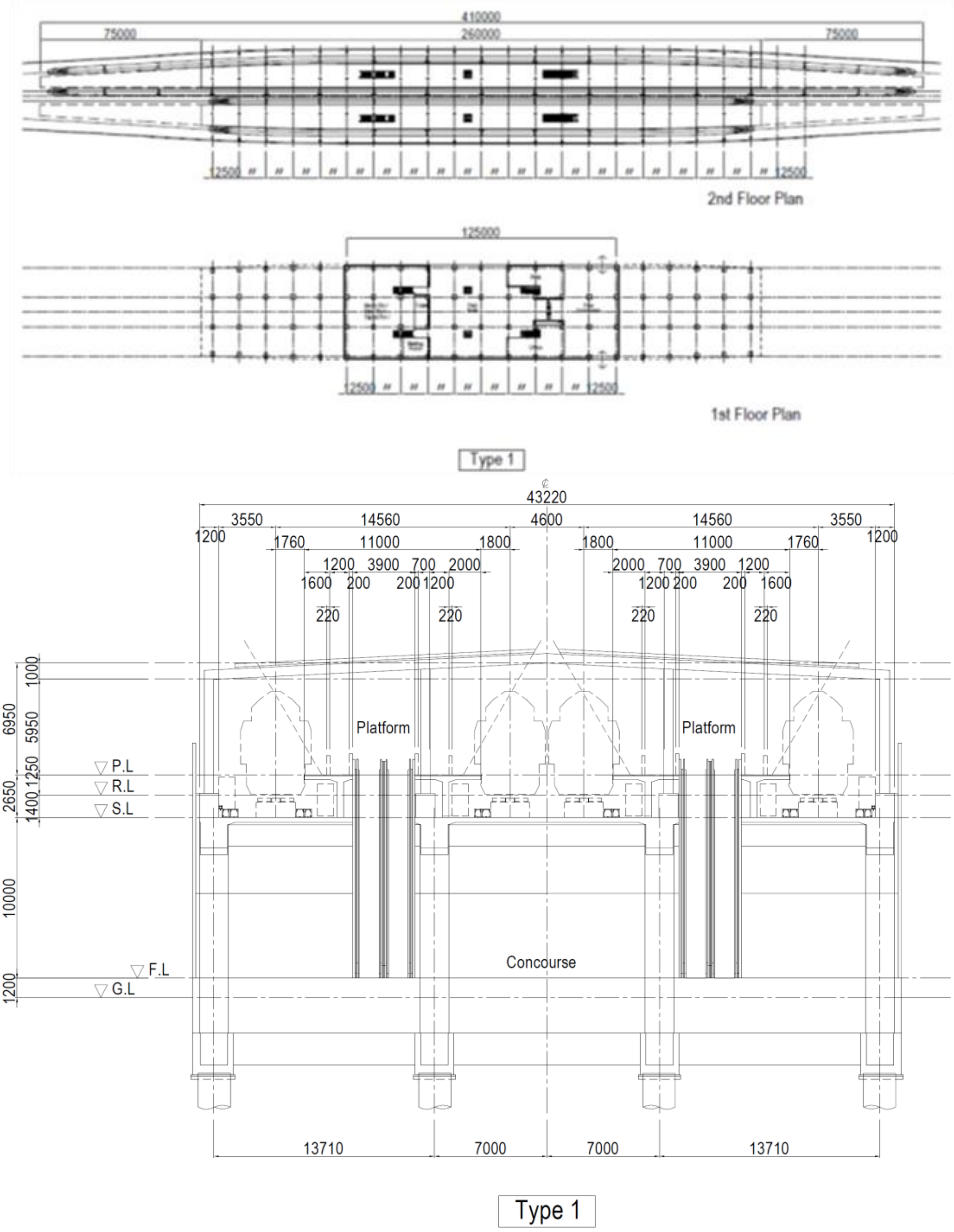
Source: JICA Study Team

(6) Proposed Station Type

1) Station Type 1

A station with a relatively high passenger volume where all trains stop.

The Type 1 station is envisioned as a two-story station. The 2nd floor would be four tracks and two island platforms, and the 1st floor the concourse.



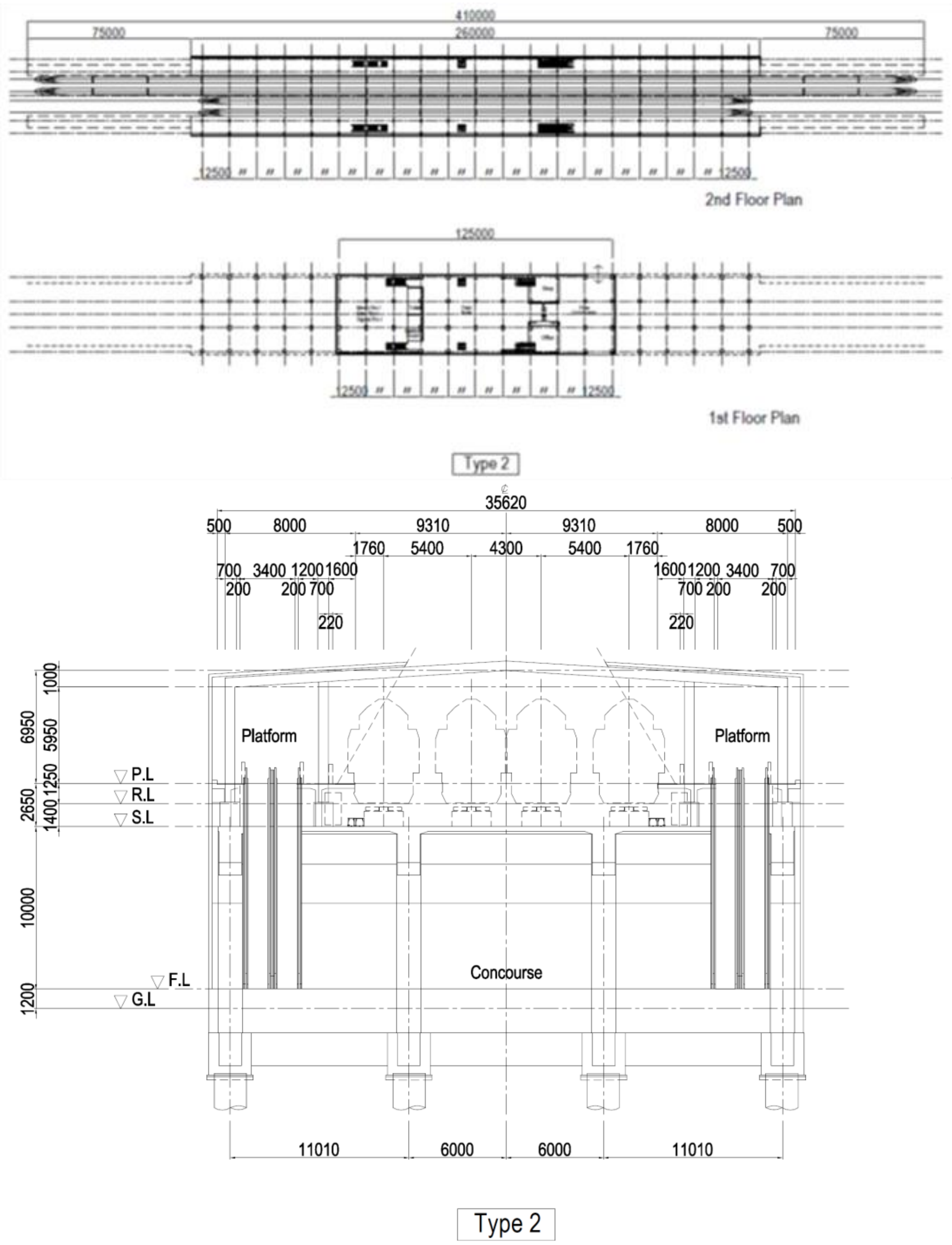
Source: JICA Study Team

Figure 4.25: Drawing of Station Type 1

2) Station Type 2

A station with a relatively low passenger volume where only local trains stop. While the local train is stopped, the express train will pass through the passing line and will overtake the local train.

The Type 2 station is envisioned as a two-story station. The 2nd floor would be four tracks and two opposite platforms, and the concourse on the 1st floor.



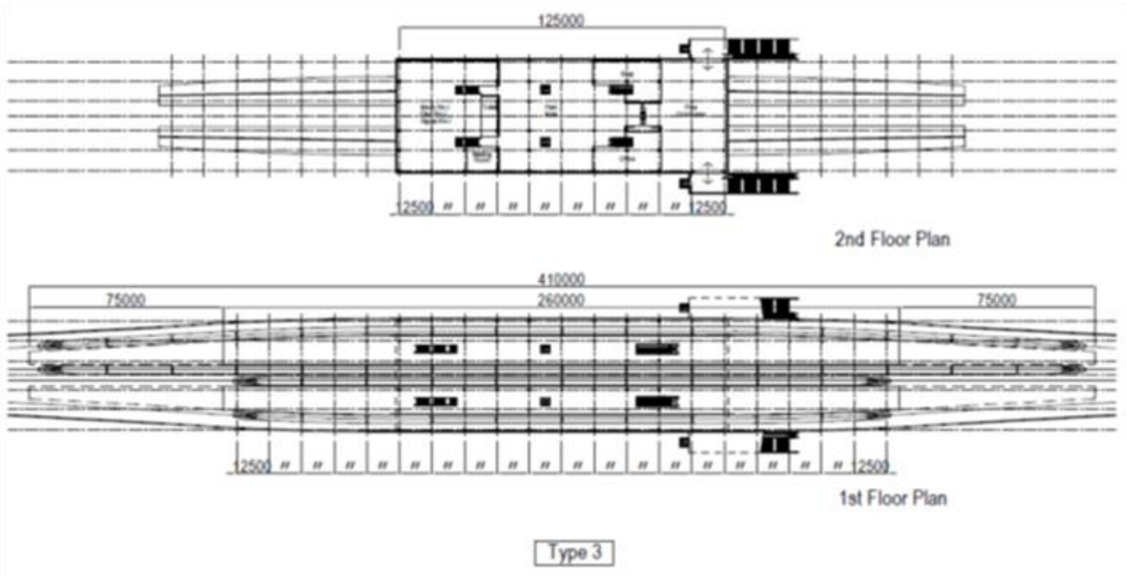
Source: JICA Study Team

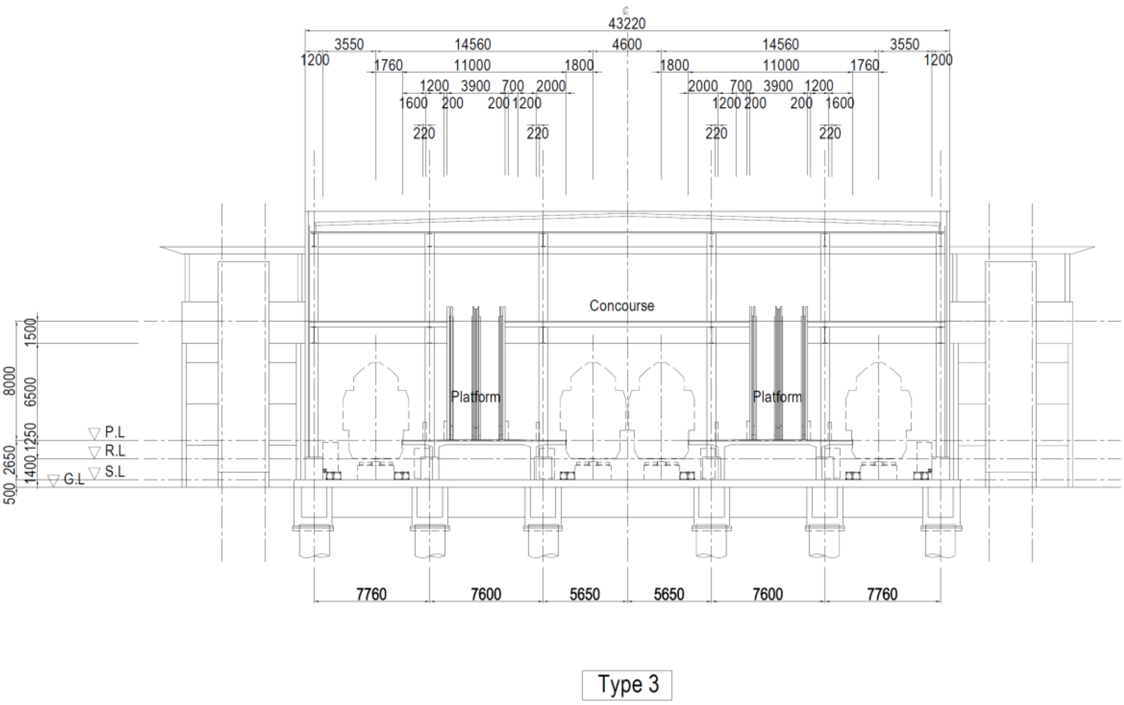
Figure 4.26: Drawing of Station Type 2

3) Station Type 3

A station with a relatively high passenger volume where all trains stop.

The Type 3 station is envisioned as a two-story station. A concourse on the 2nd floor and on the ground floor (1st floor) there would be four tracks and two island platforms.





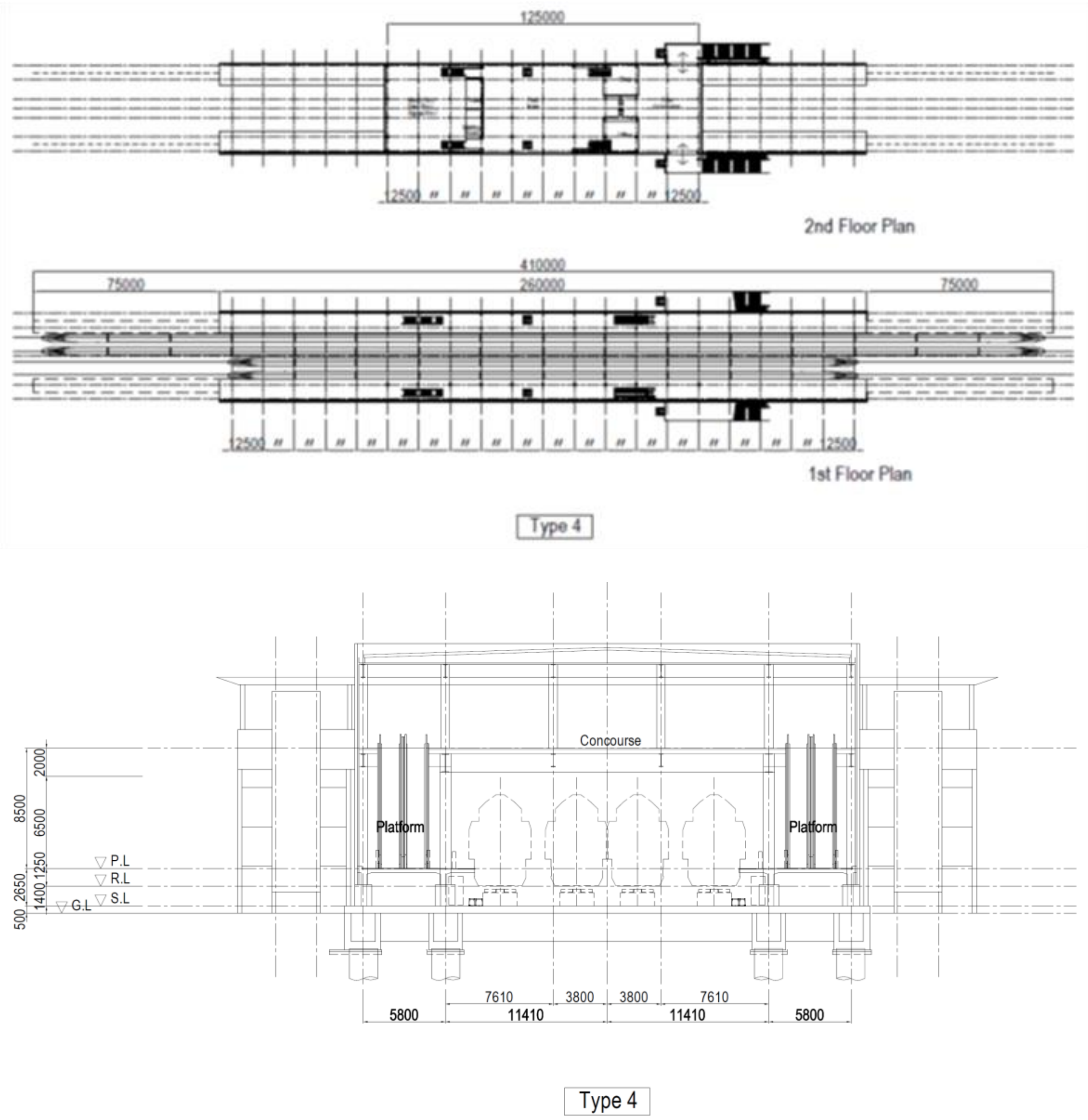
Source: JICA Study Team

Figure 4.27: Drawing of Station Type 3

4) Station Type 4

A station with relatively low passenger volume where only local trains stop. While the local train is stopped, the express train will bypass it via the passing line.

The Type 4 station is envisioned as a two-story station. A concourse on the 2nd floor and on the ground floor (1st floor) there would be four tracks and two opposite platforms.



Source: JICA Study Team

Figure 4.28: Drawing of Station Type 4

(7) Universal Design

To the greatest extent possible, it is essential for station and station facilities to equally provide safe, smooth and comfortable services and environment that are usable by everyone, regardless of age, gender, physical ability, cultural background, without the need for adaptation or specialized designs.

Looking back at the history of universal design in the United States from the 1950s, three types of movements have occurred in parallel: (i) laws brought by the disabled rights movement, (ii) movement towards barrier-free design, and (iii) movement of rehabilitation technology and assistive technology. Although these movements have advanced from a completely different history and direction, the purpose of these technologies has been the same.

Brought on by the changing economic and social circumstances, a team at the at North Carolina State University summarized and announced the concepts for *Universal Design* in 1997, as a unified universal design to promote towards the 21st century. Later, it has been legislated according to the circumstances of each country.

The following seven principles need to be considered to be compliant with the concept of universal design. However, it does not mean all the concepts need to be adopted.

(a) Equitable Use
(b) Flexibility in Use
(c) Simple and Intuitive Use
(d) Perceptible Information
(e) Tolerance for Error
(f) Low Physical Effort
(g) Size and Space for Approach and Use

Technical functionality of Universal Design for stations, station facilities, and rolling stock can be classified into five categories:

1) Space for Moving
2) Space for Acting
3) Information
4) Environment
5) Safety and Security

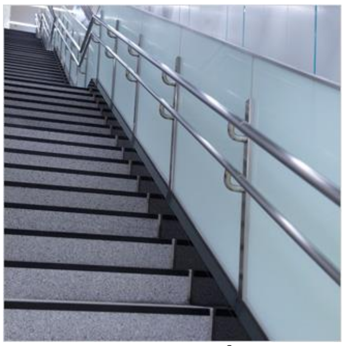
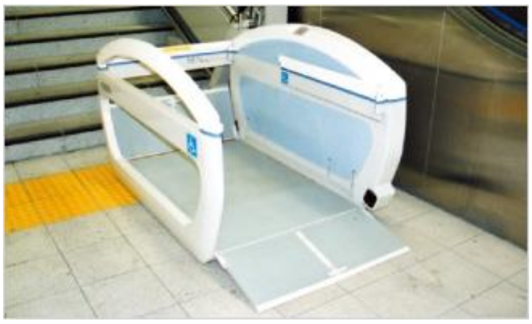
The below table shows examples of universal design that are adopted in Japan.

1) Space for Moving

Table 4.12: Examples of Universal Design (Space for Moving)

Items	Social Considerations by Universal Design	Examples
Automatic Ticket Gate	Some of the gates are wider for passengers utilizing wheelchairs and passengers who have large baggage.	 (Source: Tokyo Metro[1])
Elevator	Elevators with windows that can be seen from both inside and outside are installed so that the passengers can recognize where he/she is and doesn't have to experience the anxiety of being in a closed space. The elevator buttons are simple and easy to operate.	 (Source: Tokyo Metro[2])
Escalator	Audio guidance and caution signs are installed near the end of the escalator to notify the passengers to watch their steps.	 (Source: Tokyo Metro[3])
Slope	Steps are avoided as much as possible for the elderly and wheelchair users to avoid stumbling.	 (Source: Tokyo Metro[4])

1 https://www.tokyometro.jp/safety/barrierfree/facilities/index.html (Referenced 2019.06.10)
2 Same as above
3 Same as above
4 Same as above

Items	Social Considerations by Universal Design	Examples
Braille Block/Tile	Blocks/tiles following the directed traffic lines are installed. Different tiles are utilized with dotted blocks for reminder and lined patterns for leading. These blocks/tiles can also be a cornerstone or a reminder sign for all kinds of passengers.	 (Source: Tokyo Metro[5])
Double Handrail	Double handrails are installed for the elderly and children.	 (Source: Tokyo Metro[6])
Stair Lift	With the stairlift, passenger can ascend the stairs without getting off their wheelchair.	 (Source: Tokyo Metro[7])
Movable step	Movable steps extend automatically to assist wheelchair users to get on the train.	 (Source: Nippon Foundation Library[8])

5 https://www.tokyometro.jp/safety/barrierfree/facilities/index.html (Referenced 2019.06.10)
6 Same as above
7 Same as above
8 https://nippon.zaidan.info/seikabutsu/2005/00250/contents/0002.htm (Referenced 2019.06.10)

Items	Social Considerations by Universal Design	Examples
Gangplank	Station staff deploy the gangplank to assist wheelchair users to board the train.	 (Source: IYOTETSU[9])

Source: JICA Study Team

2) Space for Acting

Table 4.13: Examples of Universal Design (Space for Acting)

Items	Social Considerations by Universal Design	Examples
Multifunction Toilet	The entrances for both men and women are clearly separated and identified. The bedpan washer button, toilet paper holder, and emergency call button are placed on the wall within easy reach. Enough space for wheelchair users is provided. Toilets shall be functional and comfortable for any type of user.	 (Source: Tokyo Metro[10])
Automatic Ticket Vending Machine	The coin slot is placed at a lower and wider spot for the elderly and children. The numeric keypad, audio guidance for visually disabled persons, and a small area for baggage are also factored in.	 (Source: Tokyo Metro[11])

Source: JICA Study Team

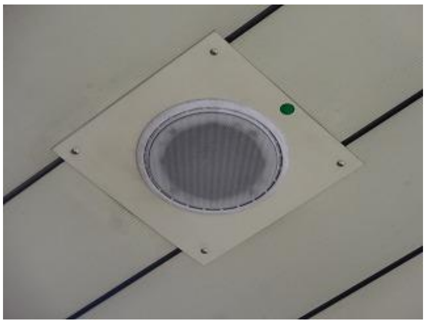
[9] https://www.iyotetsu.co.jp/sp/company/free/station.html(2019.06.10)
[10] https://www.tokyometro.jp/safety/barrierfree/facilities/index.html (2019.06.10)
[11] https://www.tokyometro.jp/safety/barrierfree/facilities/index.html (2019.06.10)

3) Information

Table 4.14: Examples of Universal Design (Information)

Items	Social Considerations by Universal Design	Examples
Destination Information Board	Easy-to-understand guide displays are installed in the station, the platform, and in the train.	 (Source: Urban Renaissance Agency[12])
Pictogram	Signs are installed at the corner and higher places on the wall so that all passengers can see.	 (Source: Toei Subway Disaster prevention handbook[13])
Braille Fare Table	It shall be installed near the ticket booth at all stations.	 (Source: Tokyo Metro[14])
Tangible Map	Tangible maps with braille are installed in the concourse to assist with the way to each destination by audio guidance. The present location should be indicated on the map.	 (Source: Tokyo Metro[15])

12 https://www.ur-net.go.jp/aboutus/action/ud/ud_08.html(2019.06.10)
13 https://www.kotsu.metro.tokyo.jp/subway/index.html (2019.06.10)
14 https://www.tokyometro.jp/safety/barrierfree/facilities/index.html (2019.06.10)
15 https://www.iyotetsu.co.jp/sp/company/free/station.html (2019.06.10)

Items	Social Considerations by Universal Design	Examples
Audio Assist	For visually disabled persons, audio assistance devices are installed at the ticket gate, toilet, near the stairs, escalator, elevator, and entrances of the station.	 (Source: Railway laboratory net[16])

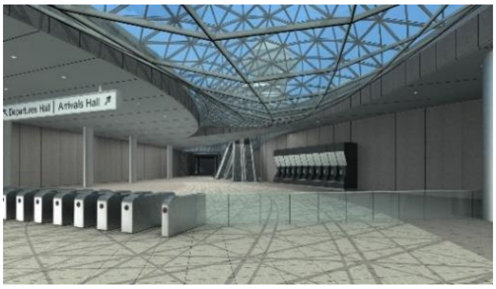
Source: JICA Study Team

4) Environment

Table 4.15: Examples of Universal Design (Environment)

Items	Social Considerations by Universal Design	Examples
Artworks	Stained glass that expresses the features of each station, pottery board, etc. are installed.	 Shinjuku 3-chome Station (Source: Railway Architecture News, 2009)
Open Ceiling Space	High ceilings are utilized where possible, to create an open environment.	 Meiji-Jingu Station (Source: Railway Architecture News, 2009)

[16] https://tetsuken.ninja-web.net/ekigaido/ettyuujima.html (2019.06.10)

Items	Social Considerations by Universal Design	Examples
Skylight	Natural light is captured as much as possible.	 Bucharest Project (Source: JICA Study Team)
Measures of Train Wind Reduction	An example of the most effective full-screen platform doors.	 Shiroganedai Station (Source: JICA Study Team)

Source: JICA Study Team

5) Safety and Security

Table 4.16: Examples of Universal Design (Safety and Security)

Items	Social Considerations by Universal Design	Examples
Emergency Call System	Station staff can be contacted quickly through this system in case of emergencies.	 Shiroganedai Station (Source: JICA Study Team)
Emergency Stop Switch	The kill switch will stop the train in emergencies.	 Tokyo Station (Source: JICA Study Team)

Items	Social Considerations by Universal Design	Examples
Platform Screen Door	The screen door is set between the train and platform, which prevents passengers from falling.	 Tokyo Station (Source: JICA Study Team)
Doors for Toilet	In order to reduce the blind spots for crime prevention, doors are only installed at multipurpose toilets and private rooms inside of toilets.	 Minato Mirai Station (Source: Railway Architectural News, 2006)
AED	AEDs are installed in various places where passengers can access immediately during emergencies.	 Tokyo Station (Source: JICA Study Team)

Source: JICA Study Team

6) Universal Design for Rolling Stock

Concept of Universal Design should also be applied to Rolling Stock. The following table shows the operative examples:

Table 4.17: Examples of Universal Design (Rolling Stock)

<table>
<tr><th>Items</th><th>Social Considerations by Universal Design</th><th>Examples</th></tr>
<tr><td>Braille Guide Plate</td><td>Braille guide plates are installed at entrances of the trains at all stations for the visually disabled passengers.</td><td>
(Source: JICA Study Team)</td></tr>
<tr><td>Broad entrance</td><td>A wide entry / exit for passengers on wheelchairs are incorporated.</td><td>
Tokyo Station
(Source: JICA Study Team)</td></tr>
</table>

Source: JICA Study Team

4.2 Power Supply System

4.2.1 Electric Power System

(1) Vietnamese Electricity System

In Vietnam, the Ministry of Commerce and Industry (MOIT) has jurisdiction over the field of electricity and energy, and the Institute of Energy (IE) under the MOIT formulates energy policy planning and power development plans.

The Vietnam Power Group (EVN: Vietnam Power Group) owns and manages power generation companies, load dispatching center, power transmission companies, and power distribution companies for the power network system. Among them, the 500 kV, 220 kV networks are managed by the National Power Transmission Corporation (NPT).

The 220 kV transmission system, 110 kV transmission system and distribution system are managed by the following five power corporations:

- Northern Power Corporation (NPCEVN)
- Central Power Corporation (ENVCPC)
- Southern Power Corporation (EVNSPC)
- Hanoi Power Corporation (EVNHANOI)
- Ho Chi Minh City Power Corporation (EVNHCMC)

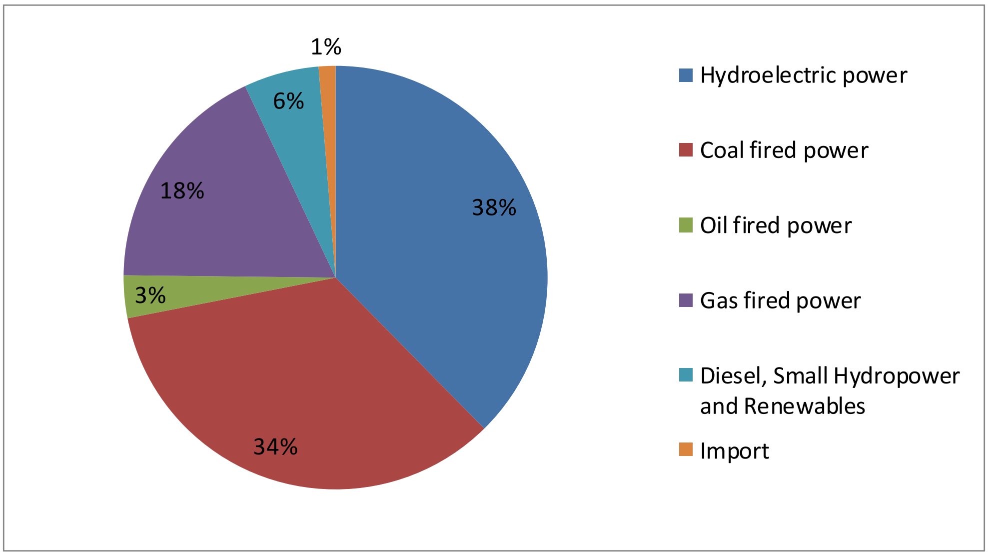
(2) Present Status of the Electric Power Sector

As shown in the table and the figure below, hydroelectric power plants and coal-fired power plants comprises 72% of the generator capacity of the power system in Vietnam. Because of the high ratio of hydroelectric power generation, it is necessary to increase the output of coal-fired power plants to secure power generation levels during droughts. As of the end of 2016, the total generating capacity is 42,135 MW.

Table 4.18: Generator Capacity by Power Plant Type (December 2016)

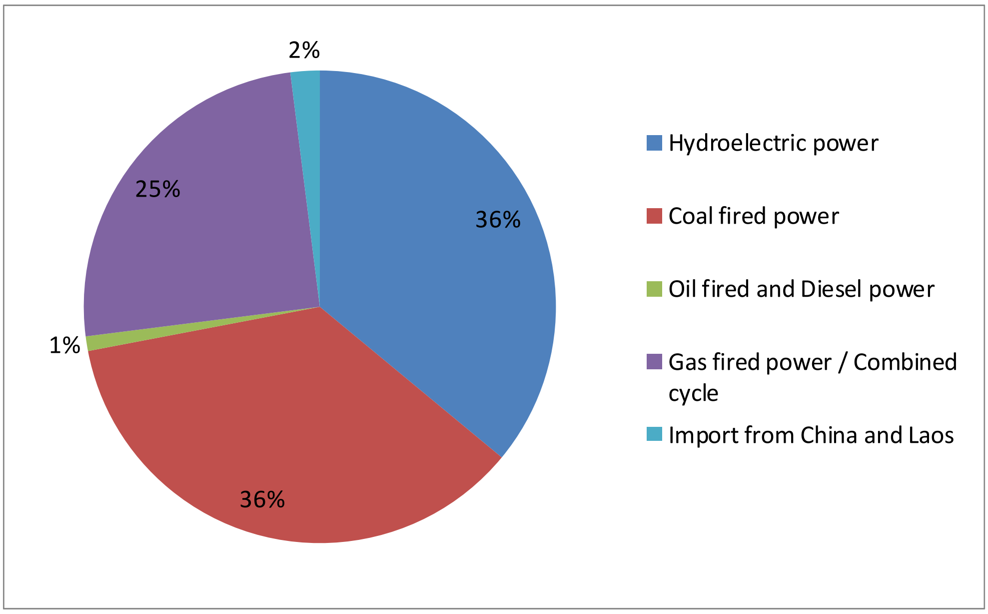
Type of Power Plant	Normal Capacity (MW)	Ratio of Power Station (%)
Hydroelectric power	15,857	37.6%
Coal fired power	14,448	34.3%
Oil fired power	1,370	3.3%
Gas fired power	7,502	17.8%
Diesel, Small Hydropower and Renewables	2,418	5.7%
Import	540	1.3%
Total	42,135	100%

Source: EVN Annual report 2017



Source: EVN Annual Report 2017

Figure 4.29: Generator Capacity by Power Plant Type (December 2016)



Source: EVN Annual Report 2017

Figure 4.30: Power Generation by Power Plant Type (December 2016)

The generated electric energy of major generators is 36% each by hydraulic power plants, and coal-fired power plants, and 25% by gas-fired power plants.

The Vietnam electric power system consists of a 500 kV, 220 kV, 110 kV primary transmission system, and the 500 kV transmission line is constructed to interconnect between the northern region and the southern region of Vietnam, while the construction of the 220 kV transmission network is divided into the northern area, Ho Chi Minh area and power generation network in the central area. The interconnection of the 220 kV transmission systems in Vietnam is planned to be completed around 2030, according to the National Power Master Plan of Vietnam. The outline of the transmission system of Vietnam is shown below.

Table 4.19: The National Power Transmission System Controlled by the National Power Transmission Corporation (NPT) (December 2016)

Item	Unit	Quantity
500kV Transmission lines	km	7,446
220kV Transmission lines	km	16,071
500kV Transformer Capacity	MVA	26,100
220kV Transformer Capacity	MVA	41,538

Source: EVN Annual Report 2017

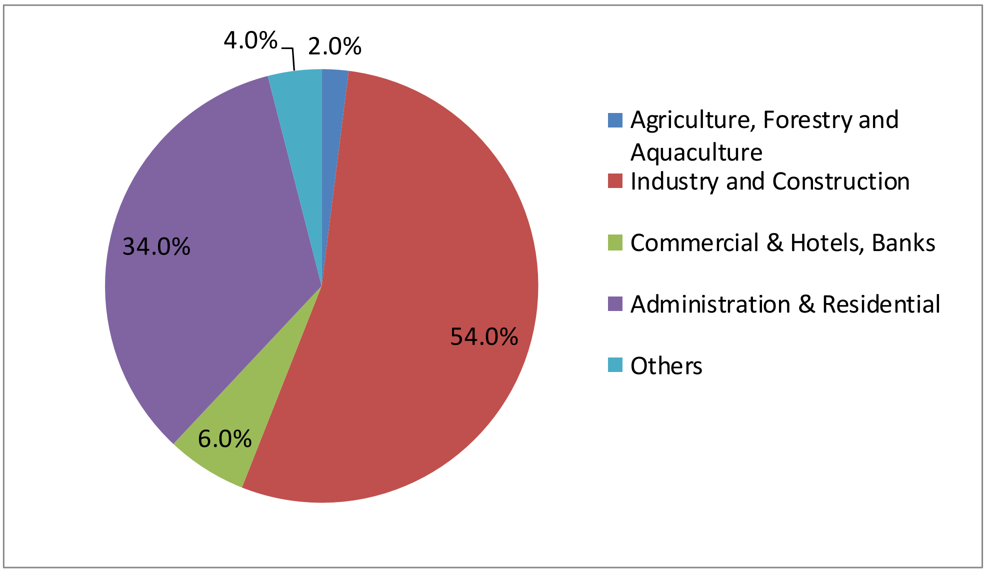
Table 4.20: The Power Distribution Networks (December 2016)

Item	Unit	Quantity
220kV Transmission lines	km	108
110kV Transmission lines	km	19,335
Medium and low voltage lines	km	495,688
220kV Transformer Capacity	MVA	3,250
110kV Transformer Capacity	MVA	52,360
Medium and low voltage Transformer Capacity	MVA	89,609

Source: EVN Annual Report 2017

The grounding system of 110 kV or more in the power transmission system is a direct neutral grounding system, making it easy to make judgments at the time of fault generation. Also, according to the national electrical regulations, the voltage fluctuation range is specified to ± 5% of the normal voltage.

The electricity power sales in Vietnam account for around 90% in industry and construction and administration and residential, as shown in the figure below. In addition, the supply growth rate has been maintained at around 10%.



Source: EVN Annual Report 2017

Figure 4.31: Power Sales by Customer Type (2016)

Table 4.21: Power Sales Growth

Year	2011	2012	2013	2014	2015	2016
Power sales Growth(%)	10.49	11.43	9.30	11.58	11.70	11.21

Source: EVN Annual Report 2017

(3) Future Planning of the Vietnamese Power System

The 7th National Power Development Plan is a future plan aiming for sufficient power supply, in order to achieve the national goal of an annual average GDP growth rate of 7% from 2016 to 2030. The total generator capacity, ratio of generation and annual power generation by power plant type are shown below.

Table 4.22: Generator Capacity by Power Plant Type within the 7th National Power Development Plan

year		2020	2025	2030
Total Capacity of Generator (MW)		60,000	96,500	129,500
Ratio of generator	Hydroelectric power	30.1%	21.1%	16.9%
	Coal fired power	42.7%	49.3%	42.6%
	Gas fired power	14.9%	15.6%	14.7%
	Renewables	9.9%	12.5%	21.0%
	Nuclear power	-	-	3.6%
	Imported	2.4%	1.5%	1.2%

Source: 7th National Power Development Plan (Vietnamese government, March 2016)

Table 4.23: Power Generation by Power Plant Type within the 7th National Power Development Plan

year		2020	2025	2030
Power Generation output (billion kWh)		265	400	572
Ratio of generator	Hydroelectric power	25.2%	17.4%	12.4%
	Coal fired power	49.3%	55.0%	53.2%
	Gas fired power	16.6%	19.1%	16.8%
	Renewables	6.5%	6.9%	10.7%
	Nuclear power	-	-	5.7%
	Imported	2.4%	1.6%	1.2%

Source: 7th National Power Development Plan (Vietnamese government, March 2016)

In the Development Plan, it is planned to decrease the ratio of hydropower generation whose output is less than 30% during the dry season and to increase the ratio of thermal power generation which is expected to provide stable power generation year-round. In addition, the capacity of hydropower generators in 2030 (which is the scheduled year for the high speed railway operation to start) is secured at around 17%, with a power supply configuration that can flexibly respond to load fluctuations. The extension plan of the power network system is shown in the table below.

Table 4.24: Forecast of Extensions in Transformer Capacities and Transmission Lines by 2030

Item	Unit	2016 - 2020	2021 - 2025	2026 - 2030
500kV Transformer Capacity of Substations	MVA	26,700	26,400	23,550
220kV Transformer Capacity of Substations	MVA	34,966	33,888	32,750
500kV Transmission lines	km	2,746	3,592	3,714
220kV transmission lines	km	7,488	4,076	3,435

Source: 7th National Power Development Plan (Vietnamese government, March 2016)

In the 7th National Power Development Plan, it is planned to strengthen the 500 kV transmission line and to construct a transmission linkage line of 220 kV between the north and south, and it is also planned that a transmission line will be constructed near the high-speed railroad route.

The plans for increasing and strengthening the transmission lines and substations are as shown in Table 4.25 to Table 4.30.

Table 4.25: Lists of 220 kV New Transformer Lines in the Northern Area

No.	Substation name	Transformer Capacity set(s) x MVA	Note
Construction Plan from 2016 to 2020			
1	Quang Chau	1 x 250	
2	Thuy Nguyen	1 x 250	
3	Lang Son	1 x 125	
4	Son Tay	1 x 250	
5	Long Bien	2 x 250	
6	West of Hanoi	2 x 250	
7	Bac Ninh 2	2 x 250	
8	Dong Anh	2 x 250	
9	Bac Ninh 3 (Yen Phong)	2 x 250	
10	Vinh Tuong	2 x 250	
11	Yen My	1 x 250	
12	Bac Ninh 4	1 x 250	
13	Truc Ninh	2 x 250	
14	Thai Thuy	1 x 250	
15	Thanh Nghi	1 x 250	
16	Ninh Binh 2	1 x 250	
17	Bao Lam	2 x 125	
18	Than Uyen	1 x 250	
19	Nghia Lo	1 x 250	
20	Lai Chau	2 x 250	
21	Phu Tho	2 x 250	
22	Bac Kan	1 x 125	
23	Muong Te	1 x 250	
24	Luu Xa	1 x 250	
25	Quynh Luu	1 x 250	
26	Vung Ang	1 x 125	
27	Nong Cong	1 x 250	
28	Bac Me	1 x 63	
29	Khe Than	1 x 63	
30	Muong La	2 x 125	
Construction Plan from 2021 to 2025			
31	Duong Kinh	1 x 250	
32	Bac Ninh 5 (Dong Ky)	1 x 250	
33	Ba Thien	1 x 250	
34	Me Linh	1 x 250	
35	Ung Hoa	1 x 250	
36	An Lao	2 x 250	In the 500kV Hai Phong Substation
37	Gia Loc	2 x 250	
38	Pho Cao	2 x 250	
39	Hai Hau	2 x 250	
40	Vu Thu	1 x 250	
41	Dong Mo	1 x 250	
42	Dai Tu	1 x 250	
43	Phu Tho 2	1 x 250	
44	Lang Giang	1 x 250	
45	Bac Ninh 4	2 x 250	
46	Gia Luong (Bac Ninh 6)	1 x 250	
47	Dien Bien	2 x 125	
48	Yen Thuy	1 x 125	
49	Yen Hung	1 x 250	
50	Sam Son	2 x 250	
51	Nam Cam	1 x 250	
52	Thach Khe	1 x 250	
Construction Plan from 2026 to 2030			
53	Dong Anh 2	2 x 250	
54	Soc Son 2	2 x 250	
55	Long Bien 2	2 x 250	
56	Chuong My	2 x 250	
57	Do Son	1 x 250	
58	Dai Ban	1 x 250	
59	Tu Ky	2 x 250	
60	Phuc Dien	2 x 250	
61	Hung Yen City	1 x 250	
62	Ly Nhan	2 x 250	
63	Nam Dinh 2	1 x 250	
64	Quynh Phu	2 x 250	
65	Tam Diep	2 x 125	
66	Luc Yen	2 x 125	
67	Song Cong	1 x 250	
68	Tam Duong	1 x 250	
69	Chu	2 x 125	
70	Thuan Thanh	2 x 250	
71	Dong Ky (Bac Ninh 7)	2 x 125	
72	Mong Cai	2 x 125	
73	Ha Long	1 x 250	
74	Tan Lac	1 x 125	
75	Hau Loc	2 x 250	
76	Ngoc Lac	2 x 125	
77	Tuong Duong	1 x 125	
78	Can Loc	1 x 125	

Source: 7th National Power Development Plan (Vietnamese government, March 2016)

Table 4.26: Lists of 220 kV New Transformer Lines in the Central Area

No.	Substation name	Transformer Capacity set(s) x MVA	Note
Construction Plan from 2016 to 2020			
1	Ngu Hanh Son	1 x 250	
2	Son Ha	2 x 125	
3	Hai Chau	1 x 250	
4	Phong Dien	1 x 125	
5	Duy Xuyen	1 x 125	
6	Kon Tum	1 x 125	
7	Dak Nong	2 x 125	
8	Chu Se	1 x 125	
9	Phu My	1 x 125	
10	Van Phong	1 x 250	
Construction Plan from 2021 to 2025			
11	Krong Ana	2 x 125	
12	Cam Ranh	1 x 250	
13	Lao Bao	1 x 125	
14	Tam Hiep	2 x 125	
15	Dung Quat 2	1 x 250	
16	Ninh Hoa	2 x 250	
17	Chan May	1 x 125	
Construction Plan from 2026 to 2030			
18	An Don	1 x 250	
19	Bac Chu Lai	1 x 125	
20	Lien Chieu	2 x 250	
21	Quang Ngai 2	1 x 250	
22	Song Cau	2 x 125	
23	Nhon Hoi	1 x 250	
24	Bo Y	1 x 125	

Source: 7th National Power Development Plan (Vietnamese government, March 2016)

Table 4.27: Lists of 220 kV New Transformer Lines in the Southern Area

No.	Substation name	Transformer Capacity set(s) x MVA	Note
Construction Plan from 2016 to 2020			
1	Duc Trong	2 x 125	
2	Ham Tan	1 x 250	
3	Vung Tau	2 x 250	
4	My Xuan	2 x 250	
5	Chau Duc	1 x 250	
6	Tan Uyen	2 x 250	In the 500kV Tan Uyen Substation
7	Tay Ninh 2	1 x 250	
8	Tam Phuoc	1 x 250	
9	Chon Thanh (Binh Long 2)	1 x 250	In the 500kV Chon Thanh Substation
10	Ben Cat	2 x 250	
11	Ben Cat 2	2 x 250	
12	District 8	2 x 250	
13	High tech zone0]	2 x 250	
14	Tan Cang	2 x 250	
15	Dam Sen	2 x 250	
16	Thu Thiem	1 x 250	
17	Tan Son Nhat	2 x 250	
18	Mo Cay	1 x 125	
19	Can Duoc	1 x 250	
20	Ben Luc	1 x 250	
21	Sa Dec	2 x 250	
22	Long Xuyen 2	1 x 250	
23	Chau Thanh (Hau Giang)	1 x 250	
24	Can Tho	1 x 250	
25	Gia Rai	1 x 125	
26	An Phuoc	2 x 250	
Construction Plan from 2021 to 2025			
27	VSIP	2 x 250	
28	Phan Ri	1 x 250	
29	Dat Do	2 x 250	
30	Bac Chau Duc	2 x 250	In the 500kV electrical substation
31	Phu My 3 industrial zone	2 x 250	
32	District 7	2 x 250	
33	Cu Chi 2	2 x 250	
34	Binh Chanh 1	2 x 250	
35	Phuoc Long	1 x 250	
36	Tan Bien	2 x 250	
37	Phuoc Dong	1 x 250	
38	Lai Uyen	2 x 250	
39	Tan Dinh 2	2 x 250	
40	Binh My	1 x 250	
41	Long Khanh	2 x 250	
42	Dinh Quan	2 x 250	
43	Nhon Trach industrial zone	2 x 250	
44	Duc Hoa 2	2 x 250	
45	Duc Hoa 3	2 x 250	
46	Lap Vo	1 x 250	
47	Chau Thanh	1 x 250	
48	Go Cong	1 x 250	
49	Duyen Hai	1 x 250	
50	My Tu	1 x 125	
51	Cai Be	1 x 250	
52	Chau Thanh	1 x 125	
53	Hon Dat circuit breaker station		
54	Nam Can	1 x 250	
55	Long Son	1 x 250	
Construction Plan from 2026 to 2030			
56	Ninh Phuoc	1 x 250	
57	Phu My City	2 x 250	
58	Nam Hiep Phuoc	2 x 250	
59	Binh Chanh 2	2 x 250	
60	Phu Hoa Dong	1 x 250	
61	Northwest of Cu Chi	1 x 250	
62	Dong Xoai	1 x 250	
63	Ben Cau	2 x 250	
64	Tay Ninh 3	2 x 250	
65	Phu Giao	1 x 250	
66	Ho Nai	2 x 250	
67	Bien Hoa	2 x 250	
68	Dau Giay	2 x 250	
69	Tan An	2 x 250	
70	Duc Hoa 4	2 x 250	
71	Thanh Binh	2 x 250	
72	Hong Ngu	1 x 250	
73	Cho Moi	1 x 250	
74	Vinh Long 3	2 x 250	
75	Ba Tri	1 x 250	
76	Vinh Thuan	1 x 250	
77	Hon Dat	1 x 250	

Source: 7th National Power Development Plan (Vietnamese government, March 2016)

Table 4.28: Lists of 220 kV New Transmission Lines in the Northern Area

No.	Transmission line section	Circuit(s) x km			Note
Construction Plan from 2016 to 2020					
1	Bao Thang - Yen Bai	2	x	117	
2	Than Uyen - Ban Chat	2	x	26	
3	Bao Lam - branch to Nho Que - Cao Bang	2	x	5	
4	Phu Tho - branch to Viet Tri - Yen Bai	2	x	7	
5	Viet Tri 500kV - branch to Viet Tri	4	x	10	
6	Nghia Lo - Viet Tri 500kV	2	x	85	
7	Muong Te - Lai Chau	2	x	80	
8	Branch to Luu Xa	2	x	5	
9	Huoi Quang - Nghia Lo	2	x	65	
10	Son Tay - branch to Hoa Binh - Viet Tri	2	x	1	
11	Dong Anh - Hiep Hoa	2	x	24	
12	Long Bien - branch to Dong Anh - Bac Ninh 2	4	x	4.5	
13	Dong Anh - Bac Ninh 2	2	x	20	
14	Pho Noi 500kV substation - Pho Noi - Pha Lai	4	x	5	
15	Pho Noi 500kV - Bac Ninh 2	2	x	30	
16	Vinh Tuong - branch to Son Tay - Viet Tri	4	x	2	
17	Bac Ninh 3 - branch to Dong Anh - Hiep Hoa	2	x	5	
18	West of Hanoi - branch to Ha Dong - Chem	4	x	12	
19	Hoa Binh - West of Hanoi	2	x	50	
20	Yen My - branch to Pho Noi - Thuong tin	2	x	2	
21	Connection to Bac Ninh 4	2	x	11	
22	Branch to Quang Chau	4	x	6	
23	Thuy Nguyen - branch to Hai Phong thermal power station - Vat Cach	4	x	2	
24	Lang Son - Bac Giang	2	x	95	
25	Hai Duong thermal power station - branch to Pha Lai - Hai Duong 2	4	x	2	
26	Hai Duong thermal power station - Pho Noi 500kV	2	x	60	
27	Thai Binh - Kim Dong	2	x	46	
28	Truc Ninh - branch to Nam Dinh - Ninh Binh	2	x	29	
29	Thai Binh - Thai Binh thermal power station	2	x	30	
30	Thai Thuy - Thai Binh thermal power station	2	x	0.5	
31	Truc Ninh - Thai Binh thermal power station	2	x	45	
32	Nho Quan - Thanh Nghi	2	x	25	
33	Ninh Binh 2 - branch to Ninh Binh - Thai Binh	2	x	19	
34	Vung Ang - Ba Don - Dong Hoi	2	x	85	
35	Trung Son hydropower plant - branch to Hoa Binh - Nho Quan	2	x	57	
36	Thanh Son - branch to Trung Son - Nho Quan	2	x	0.5	
37	Dong Van - branch to Hua Na - Thanh Hoa	2	x	0.5	
38	Hoi Xuan - branch to Trung Son - Nho Quan	2	x	16	
39	Branch to Quynh Luu	4	x	5	
40	Vung Ang - Vung Ang thermal power station	2	x	3	
41	Branch to Nong Cong	4	x	5	
42	Viet Tri 500kV - branch to Phu Tho - Viet Tri	2	x	10	
43	Khe Than - branch to Son Dong thermal power station - Trach Bach	2	x	3	
44	Van Dien - branch to Ha Dong - Thuong Tin	4	x	7	
45	Branch to Bac Me	2	x	1	
46	Muong La - branch to Son La 500kV - Son La	2	x	1.5	
47	Viet Tri - Vinh Yen - Soc Son	2	x	74	
Construction Plan from 2021 to 2025					
48	Connection to Bac Ninh 5	2	x	7	
49	Viet Tri 500kV - Tam Duong	2	x	20	
50	Tam Duong - Ba Thien	2	x	18	
51	Ba Thien - Me Linh	2	x	20	
52	Me Linh - branch to Soc Son - Van Tri	2	x	3	
53	Gia Loc - branch to Hai Duong thermal power station - Pho Noi	4	x	2	
54	Duong Kinh - branch t o Dong Hoa - Dinh Vu	4	x	3	
55	My Ly - Ban Ve	2	x	72	
56	Nam Mo 1 - branch to My Ly - Ban Ve	2	x	18	
57	Phu Tho 2 - branch to Son La - Viet Tri	2	x	5	
58	Son La - Dien Bien	2	x	126	
59	Vinh Tuong - Vinh Yen	2	x	8	
60	Yen Thuy - branch to Hoa Binh - Nho Quan	4	x	3	
61	Dong Mo - branch to Bac Giang - Lang Son	4	x	3	
62	Dai Tu - branch to Tuyen Quang - Luu Xa and Tuyen Quang hydropower plant - Thai Nguyen	4	x	3	
63	Hai Phong 500kV - branch to Dong Hoa - Thai Binh	4	x	5	
64	Hai Phong 500kV - Gia Loc	2	x	35	
65	Lang Giang - branch to Bac Giang - Thai Nguyen	2	x	2	
66	Bac Ninh 500kV - branch to Bac Ninh 2 - Pho Noi 500kV	4	x	3	
67	Bac Ninh 500kV - Bac Ninh 4	2	x	15	
68	Gia Luong (Bac Ninh 6) - branch to Bac Ninh 2 - Pho Noi 500kV	4	x	2	
69	Long Bien - Mai Dong	2	x	20	

No.	Transmission line section	Circuit(s) x km			Note
70	Dong Anh 500kV – Van Tri 2	2	x	16	
71	Vinh Yen 500kV – Ba Thien	2	x	10	
72	Vinh Yen 500kV – Vinh Yen	2	x	16	
73	Vinh Yen 500kV – branch to Ba Thien – Me Linh	4	x	3	
74	West of Hanoi – branch to Chem – Tay Ho	2	x	25	
75	Ung Hoa – branch to Ha Dong – Phu Ly	2	x	4	
76	My Dinh – branch to West of Hanoi – Chem	4	x	1	
77	Connection to Hai Phong 3 thermal power station			92	
78	Thai Binh 500kV – branch to Thai Binh – Kim Dong	4	x	5	
79	Thai Binh 500kV – Thanh Nghi	2	x	34	
80	Pho Cao – branch to Thai Binh – Kim Dong	4	x	2	
81	Vu Thu – branch to Thai Binh – Nam Dinh and Thai Binh – Ninh Binh 2	4	x	5	
82	Hai Hau – Truc Ninh	2	x	16	
83	Thanh Hoa 500kV – branch to Nghi Son – Ba Che	4	x	5	
84	Nong Cong – branch to Nghi Son – Ba Che	4	x	2	
85	Thanh Hoa 500kV – Sam Son	2	x	25	
86	Nam Cam – branch to Nghi Son thermal power station – Vinh and Quynh Luu – Vinh	4	x	3	
87	Nghi Son thermal power station – branch to Nghi Son – Vinh	2	x	10	
88	Suspension of 2nd circuit in Thanh Hoa – Nghi Son – Quynh Luu	1	x	70	
89	Thach Khe – Ha Tinh 500kV	2	x	15	
90	Ninh Binh – Tam Diep – Bim Son	2	x	27	
91	Son La – Phu Tho – Viet Tri	1	x	192	
92	Connection to Yen Hung	2	x	12	
93	Van Tri – Tay Ho	1	x	7	
Construction Plan from 2026 to 2030					
94	Luc Yen – branch to Bao Thang – Yen Bai	4	x	2	
95	Son Tay 500kV – Vinh Yen	2	x	30	
96	Son Tay 500kV – Son Tay	2	x	8	
97	Tan Lac – branch to Hoa Binh – Yen Thuy	4	x	1	
98	Tan Lac – branch to Trung Son hydropower plant	2	x	1	
99	Thai Nguyen 500kV – branch to Bac Kan – Thai Nguyen and Tuyen Quang – Thai Nguyen	4	x	3	
100	Branch to Luu Xa	2	x	3	
101	Thai Nguyen 500kV – Thai Nguyen	2	x	5	
102	Son My thermal power station – Chu	2	x	30	
103	Dong Mo – Chu	2	x	30	
104	Bac Giang 500kV – branch to Bac Giang – Thai Nguyen	2	x	10	
105	Bac Giang 500kV – branch to Bac Giang – Dong Mo	2	x	10	
106	Song Cong – branch to Phu Binh – Hiep Hoa	4	x	5	
107	New Dong Bac coal-based thermal power station (Hai Ha 500kV) – Mong Cai	2	x	38	
108	New Dong Bac coal-based thermal power station (Hai Ha 500kV) – Hai Ha	2	x	3	
109	Ha Long – Quang Ninh	2	x	10	
110	Hai Phong 500kV – Do Son	2	x	25	
111	Hai Phong 500kV – Duong Kinh	2	x	15	
112	Tu Ky – branch to Gia Loc – Hai Phong 500kV	4	x	2	
113	Phuc Dien – branch to Gia Loc – Pho Noi 500kV	4	x	2	
114	Dong Anh 500kV – Dong Ky	2	x	8	
115	Dong Anh 2 – branch to Dong Anh – Van Tri	4	x	2	
116	Soc Son 2 – branch to Dong Anh – Hiep Hoa	2	x	10	
117	West of Hanoi – branch to Ha Dong – Thanh Cong	2	x	12	
118	Chuong My – branch to Ha Dong – Ung Hoa	4	x	10	
119	Ung Hoa – branch to Ha Dong – Phu Ly	2	x	4	
120	South of Hanoi 500kV – branch to Ha Dong – Phu Ly	4	x	2	
121	Thuan Thanh – branch to Bac Ninh – Pho Noi	2	x	6	
122	Long Bien 500kV – branch to Long Bien – Mai Dong	4	x	2	
123	Long Bien 500kV – branch to Long Bien – Bac Ninh 2	2	x	5	
124	Thai Binh 500kV – Hung Yen City	2	x	15	
125	Ly Nhan – branch to Thai Binh 500kV – Thanh Nghi	4	x	2	
126	Nam Dinh 2 – branch to Nam Dinh –Ninh Binh & Vu Thu – Ninh Binh 2	4	x	3	
127	Nam Dinh 2 – branch to Truc Ninh	2	x	2	
128	Quynh Phu – branch to Hai Phong 500kV – Thai Binh I	4	x	2	
129	Thanh Hoa 500kV – Hau Loc	2	x	27	
130	Nam Dinh I thermal power station – Hau Loc	2	x	40	
131	Nam Dinh I thermal power station – Ninh Binh 2	2	x	25	
132	Nam Dinh I thermal power station – Hai Hau	2	x	10	
133	Tam Diep – branch to Bim Son – Ninh Binh	2	x	5	
134	Can Loc – branch to Vinh – Ha Tinh	4	x	2	
135	Tuong Duong – branch to Ban Ve hydropower plant – Do Luong	2	x	3	
136	Tuong Duong – branch to Nam Mo – Ban Ve	1	x	6	
137	Tuong Duong – Do Luong	1	x	118	
138	Do Luong – Nam Cam	2	x	45	

Source: 7th National Power Development Plan (Vietnamese government, March 2016)

Table 4.29: Lists of 220 kV New Transmission Lines in the Central Area

No.	Transmission line section	Circuit(s) x km			Note
Construction Plan from 2016 to 2020					
1	Ngu Hanh Son – branch to Da Nang – Tam Ky	2	x	12	
2	Dong Hoi – Dong Ha	2	x	108	
3	Dong Ha – Hue	2	x	68	
4	Phong Dien – branch to Dong Hoi – Hue	4	x	5	
5	Hoa Khanh – Hai Chau	2	x	10	
6	Duy Xuyen – branch to Da Nang – Tam Ky	4	x	2	
7	Xekaman 1 – Pleiku	2	x	133	
8	Pleiku 2 – branch to Pleiku – Se San 4	4	x	16	
9	Connection to the aluminum smelting factory	6	x	10	
10	An Khe biomass power plant – branch to Pleiku – An Khe hydropower plant	2	x	1	
11	Pleiku 2 – branch to Pleiku – Krong Buk	2	x	13	
12	Pleiku 2 – Krong Buk	1	x	141	
13	An Khe – Pleiku 2	1	x	120	
14	An Khe – Quy Nhon	1	x	46	
15	Quang Ngai – Phuoc An	2	x	135	
16	Phu My – branch to Phuoc An – Quang Ngai	2	x	2	
17	Thuong Kon Tum – Quang Ngai	2	x	76	
18	Chu Se – branch to Pleiku – Krong Buk	2	x	2	
19	Duc Trong – branch to Da Nhim – Di Linh	2	x	7	
20	Nha Trang – Thap Cham	2	x	105	
21	Van Phong – branch to Nha Trang – Tuy Hoa	4	x	3	
Construction Plan from 2021 to 2025					
22	Thanh My 500kV – Duy Xuyen	2	x	57	
23	Krong Ana – branch to Krong Buk – Buon Kuop	2	x	12	
24	Cam Ranh – branch to Thap Cham – Nha Trang	4	x	2	
25	Lao Bao – Dong Ha	2	x	52	
26	Hai Chau – Ngu Hanh Son	2	x	15	
27	Tam Hiep – Doc Soi	2	x	14	
28	Dung Quat 2 – Dung Quat thermal power station	2	x	15	
29	Dung Quat thermal power station – branch to Dung Quat – Doc Soi	4	x	1	
30	Dung Quat thermal power station – Doc Soi	2	x	5	
31	Nha Trang – Krong Buk	1	x	147	
32	Ninh Hoa – branch to Tuy Hoa – Nha Trang	4	x	5	
33	220kV circuit breaker station – 500kV electrical substation in Krong Buk – Krong Buk	4	x	30	
34	220kv circuit breaker station – 500kV electrical substation in Van Phon – Ninh Hoa	2	x	25	
35	220kv circuit breaker station – 500kV electrical substation in Van Phong – branch to Ninh Hoa – Tuy Hoa 1	2	x	25	
Construction Plan from 2026 to 2030					
36	An Don – branch to Hai Chau – Ngu Hanh Son (District 3)	2	x	1	
37	Bac Chu Lai – branch to Tam Ky – Doc Soi	4	x	3	
38	Quang Ngai 2 – branch to Doc Soi – Quang Ngai	4	x	3	
39	Bo Y – Kon Tum	2	x	60	
40	220kV circuit breaker station – 500kV electrical substation in Binh Dinh – branch to Phuoc An – Phu My	4	x	20	
41	220kV circuit breaker station – 500kV electrical substation in Binh Dinh – Nhon Hoi	2	x	22	
42	Song Cau – branch to Quy Nhon – Tuy Hoa	2	x	3	
43	Nhon Hoi – Song Cau	2	x	75	
44	Song Cau – Tuy Hoa	2	x	40	
45	Van Phong thermal power station – branch to Ninh Hoa – Van Phong	2	x	25	

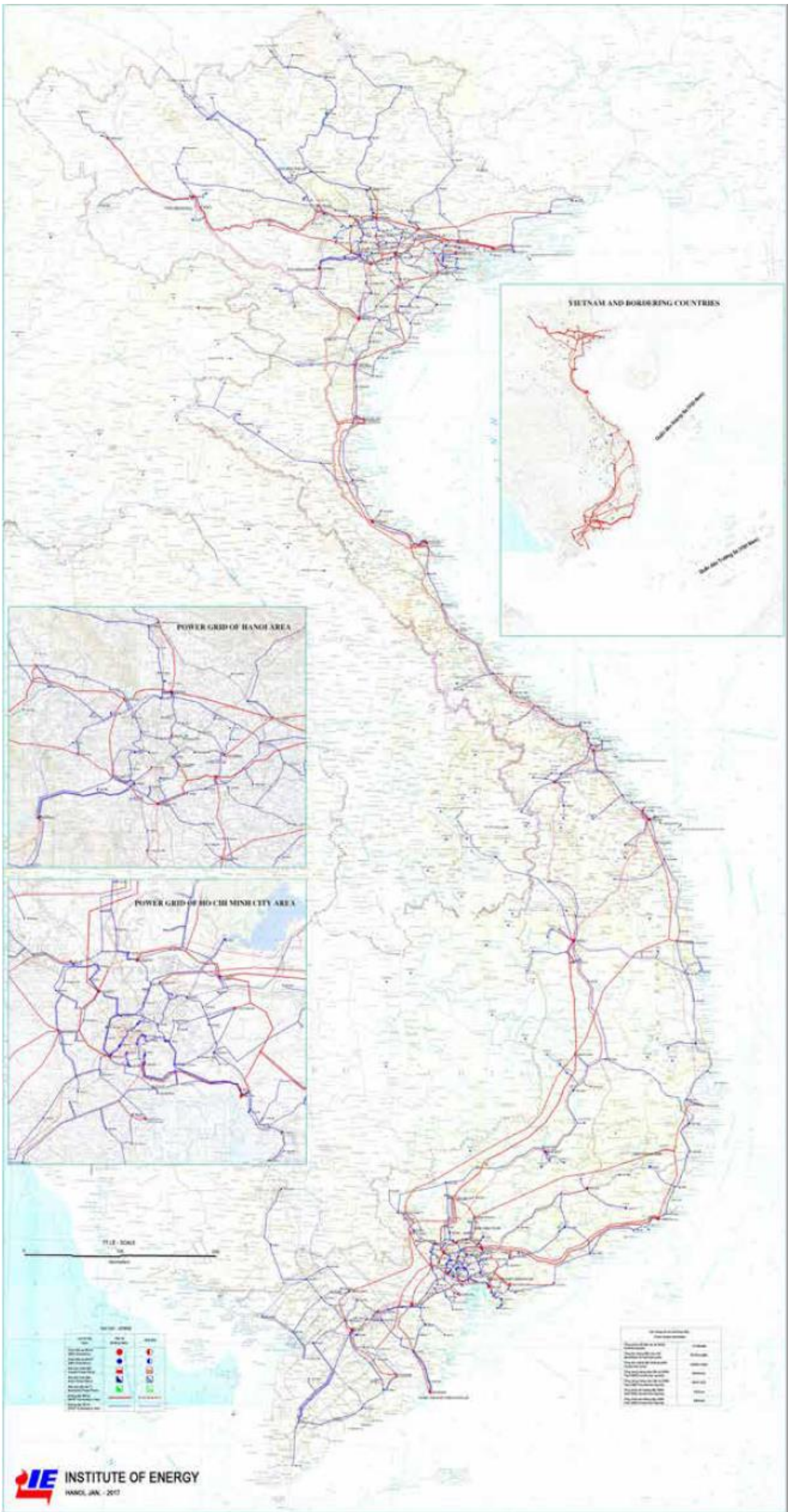
Source: 7th National Power Development Plan (Vietnamese government, March 2016)

Table 4.30: Lists of 220 kV New Transmission Lines in the Southern Area

No.	Transmission line section	Circuit(s) x km			Note
Construction Plan from 2016 to 2020					
1	Phan Thiet - Tan Thanh (Phu My 2 industrial zone)	2	x	144	
2	My Xuan - branch to Phu My - Cat Lai	4	x	0,5	
3	Ham Tan - branch to Phan Thiet - Tan Thanh	4	x	1	
4	Di Linh - Bao Loc	1	x	34	
5	Chau Duc - branch to Ham Tan - Tan Thanh	4	x	2	
6	Cau Bong - Hoc Mon - branch to Binh Tan	4	x	7	
7	Cau Bong - Duc Hoa	4	x	12	
8	High tech zone - Cat Lai	2	x	6,5	
9	Binh Chanh - District 8	2	x	6,5	
10	My Tho 500 - branch to Long An - Cai Lay	4	x	3	
11	Connection to Ben Luc	2	x	10	
12	Tay Ninh - Binh Long	2	x	64	
13	Tan Uyen - Thuan An	2	x	8	
14	Tan Uyen - branch to Thu Duc - Long Binh	4	x	8	
15	Tay Ninh 2 - branch to Trang Bang - Tay Ninh	2	x	5	
16	Tan Cang - Cat Lai	2	x	14	
17	Junction from Vinh Loc to Hoc Mon - Binh Tan	2	x	5	
18	Tam Phuoc - branch to Long Thanh - Long Binh	2	x	2	
19	Phu Lam - Dam Sen	2	x	8	
20	Connection to Thu Thiem	4	x	0,5	
21	Ben Cat - branch to Binh Long - My Phuoc	4	x	2	
22	Chon Thanh - branch to Binh Long - My Phuoc	4	x	10	
23	Chon Thanh - Ben Cat	2	x	50	
24	Hiep Binh Phuoc - Tan Son Nhat	2	x	7	
25	Bien Hoa - branch to Tan Uyen - Long Binh	4	x	1	
26	Song May - Tam Phuoc	2	x	20	
27	An Phuoc - branch to Long Binh - Long Thanh	4	x	5	
28	Can Duoc - branch to Phu My - My Tho	4	x	5	
29	Sa Dec - branch to Vinh Long 2 - O Mon	2	x	5	
30	Long Xuyen 2 - branch to Thot Not - Chau Doc	4	x	6	
31	Cai Lay - Cao Lanh (2nd generator set)	1	x	54	
32	Cao Lanh - Thot Not (2nd generator set)	1	x	27	
33	Long Phu thermal power station - Can Tho - Tra Noc	2	x	95	
34	Duc Hoa 500kV - Duc Hoa 1	4	x	22	
35	Long Phu thermal power station - Soc Trang	2	x	25	
36	Chau Thanh (Hau Giang) - branch to O Mon - Soc Trang	4	x	5	
37	Duc Hoa 500kV - branch to Phu Lam - Long An	2	x	20	
38	Dam Sen - Tan Son Nhat	2	x	6	
39	Tan Son Nhat - Thuan An	2	x	15	
40	Long Thanh 500kV - High tech zone	2	x	25	
41	Long Thanh 500kV - branch to Long Thanh - Long Binh	4	x	12	
42	Ben Cat 2 - branch to Tan Dinh - Cu Chi	4	x	2	
43	Ben Cat - Ben Cat 2	2	x	20	
44	Gia Rai - branch to Ca Mau thermal power station - Bac Lieu 2	4	x	2	
Construction Plan from 2021 to 2025					
45	Dinh Quan - branch to Bao Loc - Song May	4	x	1	
46	Phan Ri - branch to Phan Thiet - Vinh Tan	4	x	2	
47	Bac Chau Duc - branch to Tan Thanh - Chau Duc	4	x	10	
48	Son My - branch to Ham Tan - Chau Duc	4	x	4	
49	Dat Do - branch to Son My - Chau Duc	4	x	2	
50	Phu My 3 industrial zone - branch to Tan Thanh - Bac Chau Duc	4	x	6	
51	Tao Dan - Tan Cang	2	x	7	
52	Binh Chanh 1 - Cau Bong	2	x	13	
53	Cu Chi 2 - branch to Cu Chi - Cau Bong	4	x	1	
54	Thu Thiem - branch to Cat Lai - Tan Cang	2	x	2	
55	District 7 - Nha Be	2	x	6	
56	Binh Duong - branch to Uyen Hung - Song May	4	x	2	
57	Binh My - branch to Song May - Binh Duong	4	x	2	
58	VSIP - branch to Binh Hoa - Thuan An	4	x	2	
59	Tan Dinh 2 - branch to Tan Dinh - Ben Cat	4	x	2	
60	Lai Uyen - branch to Chon Thanh - My Phuoc	4	x	2	
61	Tan Bien - Tay Ninh	2	x	30	
62	220kV busway - 500kV electrical substation in Tay Ninh - branch to Tay Ninh - Trang Bang	4	x	1	
63	220kV busway - 500kV electrical substation in Tay Ninh - Phuoc Dong	2	x	36	
64	Long Khanh - branch to Long Thanh - Xuan Loc	4	x	2	
65	Nhon Trach City - Nhon Trach industrial zone	2	x	3	
66	Nhon Trach industrial zone - Long Thanh 500kV	2	x	30	
67	Duc Hoa 3 - 220kV busway and 500kV electrical substation in Duc Hoa	2	x	6	
68	Chau Thanh - branch to Chau Doc - Thot Not	4	x	2	
69	Lap Vo - 220kV circuit breaker station and 500kV electrical substation in Thot Not	2	x	22	

No.	Transmission line section	Circuit(s) x km			Note
70	Connection to Kien Giang thermal power station			20	
71	Hon Dat busway - branch to Kien Binh - Rach Gia	2	x	2	
72	Cai Be - branch to Cao Lanh - Cai Lay	4	x	3	
73	Chau Thanh - branch to O Mon - Long Phu	4	x	2	
74	My Tu - branch to Chau Thanh - Long Phu	2	x	2	
75	Ninh Kieu - branch to Tra Noc - Long Phu	4	x	4	
76	Nam Can - Ca Mau 2	2	x	55	
77	Duyen Hai 2 - branch to Duyen Hai thermal power station - Mo Cay	4	x	2	
78	Go Cong - Can Duoc	2	x	20	
79	Connection to Long An 1 thermal power station			60	
80	Long Son - branch to Chau Duc - Phu My 3 industrial zone	2	x	8	
81	Phuoc Long - branch to Binh Long - Dak Nong	2	x	5	
Construction Plan from 2026 to 2030					
82	Ninh Phuoc - branch to Thap Cham - Vinh Tan	4	x	2	
83	Ho Nai - branch to Song May - Tam Phuoc	4	x	2	
84	Phu My City - branch to Bac Chau Duc - Phu My 3 industrial zone	4	x	8	
85	Phu Giao - branch to Uyen Hung - Binh Duong 1	4	x	4	
86	Phu Hoa Dong - branch to Cu Chi 2 - Cu Chi	4	x	2	
87	Cu Chi 3 - 220kV busway and 500kV electrical substation in Cu Chi	2	x	5	
88	Tay Ninh 3 - branch to Tay Ninh 2 - Tay Ninh 1 busway	4	x	3	
89	220kV circuit breaker and 500kV electrical substation in Tay Ninh - branch to Tay Ninh 2 - Trang Bang	4	x	2	
90	Binh Long 2 - branch to Binh Long - Chon Thanh	4	x	4	
91	Ben Cau - branch to Tay Ninh 2 busway - Trang Bang	4	x	4	
92	Duc Hoa 4 - 220kV busway and 500kV substation in Duc Hoa	2	x	7	
93	220kV busway and 500kV electrical substation in Duc Hoa - branch to Phu Lam - Ben Luc	2	x	20	
94	Binh Chanh 2 - branch to Phu Lam - Duc Hoa busway	4	x	2	
95	Dau Giay - 220kV busway and 500kV electrical substation in Dong Nai 2	2	x	20	
96	Bien Hoa - branch to Long Binh - Tan Uyen busway	4	x	2	
97	Hong Ngu - Chau Doc	2	x	34	
98	Hong Ngu - 220kV busway and 500kV electrical substation in Dong Thap	2	x	24	
99	Thanh Binh - 220kV circuit breaker station and 500kV electrical substation in Dong Thap	2	x	7	
100	Cho Moi - 220kV busway and 500kV electrical substation in Dong Thap	2	x	12	
101	Cho Moi - Chau Thanh	2	x	15	
102	Vinh Thuan - branch to Rach Gia - Ca Mau thermal power station	2	x	2	
103	220kV busway and 500kV electrical substation in Tien Giang - branch to Vinh Long 2 - Sa Dec	4	x	15	
104	220kV busway and 500kV electrical substation in Tien Giang - branch to Cao Lanh - Cai Be	4	x	4	
105	Vinh Long 3 - branch to Vinh Long 2 - Tra Vinh	4	x	2	
106	Ba Tri - Ben Tre	2	x	18	
107	Tan An - branch to My Tho - Can Duoc	4	x	5	
108	Connection to Long An 2 thermal power station			62	
109	Dong Xoai - Chon Thanh	2	x	39	
110	Nam Hiep Phuoc - branch to Phu My - Can Duoc	4	x	2	
111	Connection to Tan Phuoc power center			120	

Source: 7th National Power Development Plan (Vietnamese government, March 2016)



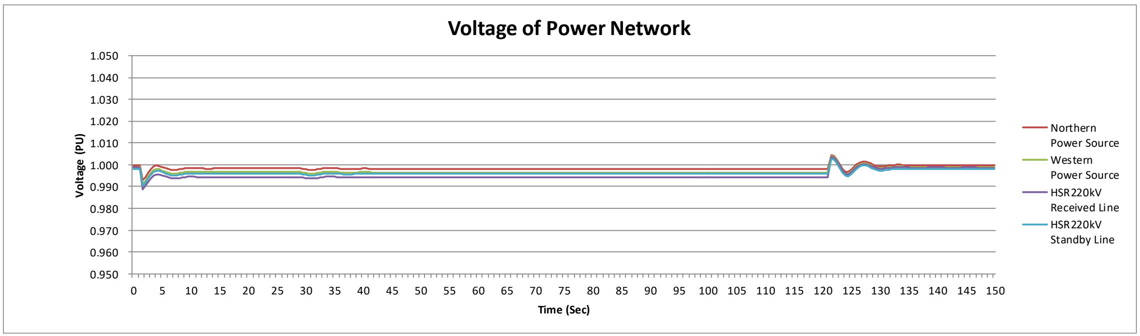
Source: EVN Annual Report 2017

Figure 4.32: Vietnam Power Systems

(4) Power Supply to High Speed Railway

The power supply to the high-speed railway is determined by considering the voltage fluctuation range, the maximum load of the high-speed railway, and the short circuit capacity of the power network system. The value allowable for voltage fluctuation stipulated in the national electrical regulations is ± 5% of the standard voltage during normal operation. In the case of four trains operating every hour, the maximum load of the high-speed railway is the electric power supplied simultaneously to a total of five trains (one express and four local trains). The reactive power of maximum load from the feeding transformer capacity is 25 MVAR. Therefore, the required short circuit capacity when suppressing the voltage fluctuation to within 5% is greater than 500 MVA. From this short circuit capacity, it is possible to supply from the 110 kV transmission network. However, it is preferable to supply from the 220 kV transmission network equivalent to the transmission voltage of 275 kV supplied in Japan, considering supply reliability.

As a result of simulation with the simple power supply model, the voltage fluctuation is about 1.1%, which is considered to be within the value allowable for voltage fluctuation in the national electrical regulations.



Source: JICA Study Team

Figure 4.33: Results of Simulation for System Voltage Fluctuation

Basically, the power transmission line for the high-speed railway substations shall be connected by its branch line from the existing transmission line. However, if the high-speed railway substation is located near the substation of the power network, an exclusive transmission bay to supply power for the high-speed railway shall be newly constructed at the substation.

The cost of the equipment to be supplied from the electric power system to the high-speed railway can be estimated from the following costs.

- The cost of connection transmission line construction
- The modification cost for transmission tower and some equipment to branch from the existing transmission line
- The cost of an exclusive transmission bay at the substation

As the plan progresses further to the basic planning stage, it is necessary to file an application for power supply for high speed railway substations to EVN after determining the substation position of the high-speed railway. At that stage, it is desirable to conduct the study of the comprehensive power receiving system to connect to high speed railway substations.

4.2.2 Power Supply System for HSR

(1) General

The power supply system is one of the most important components of an electrified transport system. It provides power in a stable and reliable manner to the electrical equipment and facilities of the line.

Studies need to be carried out to provide recommendations for options of power supply systems to be used under the project. Generally, the selection of power supply is based on the below criteria, which are classified in order of importance. Consumers, however, as far as requirements are concerned, can decide on the criteria they think is the most crucial.

- **Stability and reliability**: The power supply system shall provide stable and reliable provision of power so as to ensure optimal conditions for the operation of transport and equipment, such as the; signaling system, electric equipment of stations, lighting, ventilation system, etc. The level of stability and reliability is measured by percentage of change in supplying nominal power (%).

- **Availability**: Incidents or failure might occur inevitably during operation and exploitation. For this reason, the system shall ensure that failure of one equipment would not cause harm to the overall operation and exploitation of the line as a whole.

- **Safety and environmental protection**: There criterion is required to ensure best conditions for electricity safety, and minimize negative impacts on environment and people or radio and telecommunication infrastructure.

- **Economic criterion**: This criterion is required to optimize investments and operating costs so as to enhance the economic effectiveness, such as recovery of initial cost of investment, minimizing electronic waste in operation, etc.

- **Aesthetic element**: This is also a requirement directly relating to general landscape and environment conditions, especially urban areas, which needs to be considered.

(2) Power Supply System

1) Power Transformation System

i) Feeding System

Since the Tokaido Shinkansen started its commercial operation in Japan in October 1964, Sanyo Shinkansen, Tohoku Shinkansen, and Joetsu Shinkansen also entered into service one after another. In recent years, Hokuriku Shinkansen (Takasaki–Nagano) was launched in 1997, followed by Kyushu Shinkansen (Yatushiro–Kagoshima-Chuo). The operations of these Shinkansen have been very successful.

The system being proposed here is the latest system and is highly reliable. It combines the proven technology of the Japanese Shinkansen developed over many years, and the cutting-edge technology of power electronics, which has made tremendous advances in the recent years.

ii) Voltage of Overhead Contact Line

The below table shows the voltage of overhead contact line for the proposed Shinkansen.

Table 4.31: Voltage of Overhead Contact Line

Classification	Voltage
Highest voltage	30 (kV)
Standard voltage	25 (kV)
Lowest voltage	22.5 (kV)
Instantaneous lowest voltage	20 (kV)

Source: JICA Study Team

iii) Feeding Methodology

Electricity is supplied to the electric rolling stock through overhead contact lines and rails for operation. As the rails, which are in contact with the ground, are the return circuit of the feeding circuit, a portion of the return current flows to the ground through the rails.

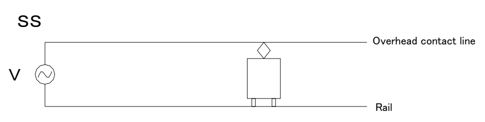
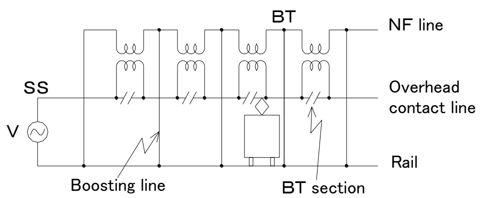
In the case of an AC electric railway, the outflow current is induced to the nearby communication lines, causing inductive problems to the communication lines. A feeding system shall be adopted as a measure to control the outflow of the current.

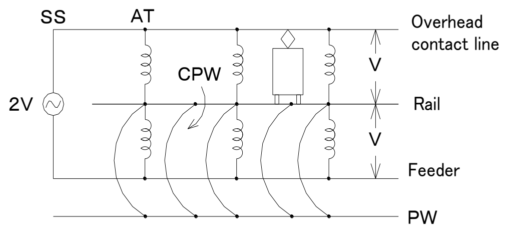
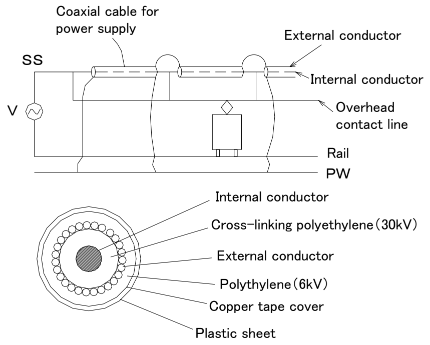
There are four major types of feeding systems: "simple feeding system," "boosting transformer feeding system," "auto-transformer feeding system" and "coaxial cable feeding system." The below table shows the characteristics of each system.

Of the systems, the autotransformer feeding system has many characteristics that are suitable for the Shinkansen. For example, it “can have a longer interval between substations,” it is “effective in reducing induction to communication lines,” and it “can control the leakage of current from the rails to the ground.” For this reason, the "auto-transformer (AT) feeding system" is recommended for the Shinkansen, which requires a high density/high volume power supply.

In general, the autotransformers are installed at standard intervals of 10 to 15 km. For this project, the autotransformers shall be installed at substations, sectioning posts, sub-sectioning posts, and AT-posts. The rated self-capacity of each autotransformer is “5MVA.”

Table 4.32: Characteristics of Various Feeding Systems

Type	Characteristics	Conceptual Drawing
Simple feeding system	• The simplest feeding system • Little induction to communication lines • Need measure to tackle insulator flashover, etc. • Higher rail electric potential than other feeding systems	
Boosting transformer feeding system	• A feeding system that uses a boosting transformer • Effective in reducing induction to communication lines • Needs a BT section • Complicated contact wiring in the BT section • Considerable impedance in the feeding system	

Type	Characteristics	Conceptual Drawing
Auto-transformer feeding system	• Suitable for supplying high electricity volume because it can carry feeding voltage (power sent out from a substation) higher than that carried by an overhead contact line • Can have a longer interval between substations than the other feeding systems • Does not need BT or other sections • Approximately a 10-km interval between two autotransformers	
Coaxial cable feeding system	• High inverse barometer effect is effective in reducing induction to communication lines • Does not need BT or other sections, simple conductor arrangement, suitable for narrow and small sections • Expensive cables • Reciprocating impedance is about 1/7 of the overhead contact line • Need to pay attention to resonance with the harmonic current	

Source: JICA Study Team referring to the previous study (JICA, 2013), etc.

iv) Feeding Transformer

- Types of Feeding Transformers

If a single-phase power supply is used to operate a Shinkansen train from a three-phase power system, it will become inversely proportional to the short-circuit capacity of the power supply on the three-phase side, thus generating reverse-phase power voltage and causing various problems to the conventional three-phase devices. Therefore, maintaining a balanced electrical current on the three-phase side becomes essential.

For this reason, the AC feeding system in Japan has been converted from a three-phase power system to a two-phase power system. Different feeding circuits are used for the up and down lines so that the electric currents in each phase of the three-phase system can be as balanced as possible. (The rate of voltage imbalance shall be negotiated with the utility company.)

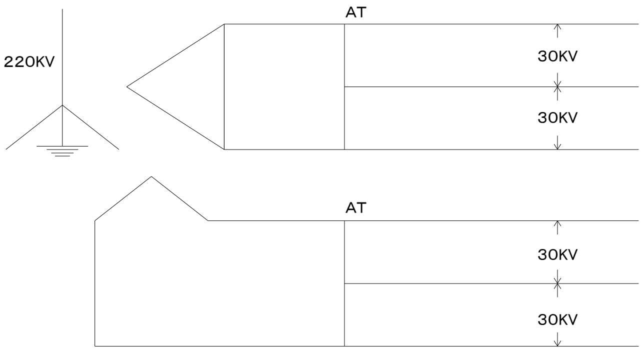
Three types of transformers are available for conversion from a three-phase system to a two-phase system, namely, the “Scott connection transformer,” “Woodbridge connection transformer,” and “Roof Bridge connection transformer.” They are used based on the power voltage received.

As a 220-kV power grid will be constructed in Vietnam by 2020, the cost-effective “Roof Bridge connection transformer” should be used.

*If a Shinkansen is powered by a high voltage of 220 kV or 275 kV, the Woodbridge connection transformer would be used because it provides direct connection to the ground at a neutral position of the three phases.

- Roof Bridge connection transformer

  The Roof Bridge connection transformer was developed recently to replace the Woodbridge transformer. This new light-weight transformer simplifies its structure by eliminating the step coil and reducing the coil volume. The below figure shows the connection wiring diagram of the transformer. The main transformer combines the Y-ΔΛ connection wiring. If the impedance of each of the main transformer's three phases is balanced, even if the primary neutral point is connected to the ground, the added current will not flow to the neutral point.



Source: JICA Study Team referring to the previous study (JICA, 2013), etc.

Figure 4.34: Connection Wiring Diagram of the Roof Bridge Connection Transformer

- Secondary Output Voltage of Feeding Transformer

  The secondary output voltage of the feeding transformer is fed at the highest voltage that the overhead contact line can handle. With the auto-transformer system, the secondary output voltage of the feeding transformer is "60 kV." To cope with the power supply fluctuations, a primary tap (non-voltage tap) switching system is utilized, making it possible to adjust to the highest voltage that the feeding circuit permits.

v) Configuration of the Feeding Circuit

- Types and Allocation of Substations

  With the AC feeding system, the adjacent substations have a different phase of power supply. Therefore, a sectioning post (SP) is installed midway between the substations. Although constraints in the installation of substations for this project have not been clarified, the capacity of feeding transformers is examined based on the assumption that the feeding section interval between the substations is approximately 80 km, with 40 km on each side. The study result indicated that 21 substations and 20 sectioning posts will be required.

  Between a substation and a sectioning post, a sub-sectioning post (SSP) is set up. This makes it possible to isolate the section in the feeding system during maintenance or when an accident occurs. An AT post (ATP) is put in place to provide relief when there is a drop-in voltage and to mitigate inductive problems triggered by a low-voltage circuit.

  There will be 82 sub-sectioning posts and seven AT posts. The positions of the SSP are determined, taking into account the feeding distance, the location of AT posts, station positions, and cost-effectiveness, etc.

Once commercial operations end for the day, feeding from the substations to the mainline will also stop so that maintenance can be carried out. The car depots, however, will continue to need power to perform maintenance on the rolling stock and to air-condition the cars to prepare them for early morning operation. For this reason, the car depots need a power supply system that is separate from the feeding system to the mainline.

There are two ways to supply power to the car depots: by setting up a dedicated substation or by getting dedicated power supply from the nearest substation. The latter is preferred due to cost efficiency.

In long tunnels, sectional disconnectors shall be installed in order to be able to divide the power supply during accidents.

- Area Distinction Feeding System

  An area distinction feeding system shall be adopted. It will direct the voltage from the transformer's main phase and teaser phase to the left and right feeding circuits of the substation, respectively.

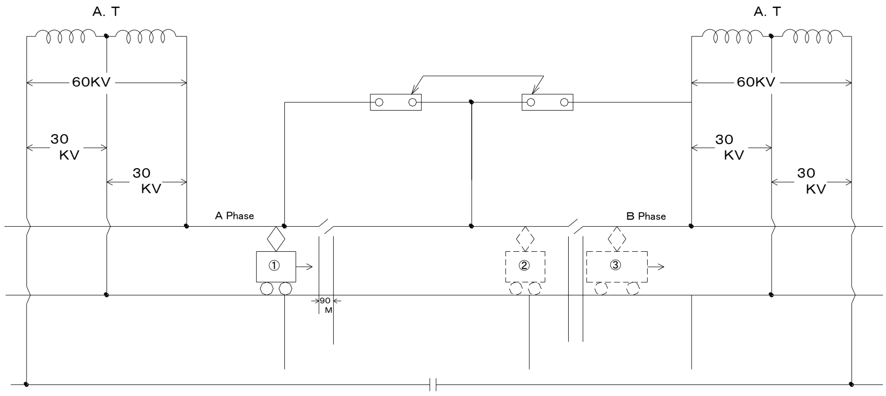
- Operation of the Feeding System

  - Up-and-down tie facility: The up-and-down tie facility is a system that connects the up and down overhead contact lines with the feeding wires at substations (SS), sectioning posts (SP), and sub-sectioning posts (SSP) on a double-track section that uses a multi-directional feeding system. This system is effective in mitigating voltage drops in the feeding circuit, and in suppressing arc in the up-and-down transitional section of a train.

  - Simultaneous up-and-down line feeding: The simultaneous up-and-down line feeding is a system that feeds power simultaneously using the up-line and the down-line of a substation. Even though it is a simultaneous up-and- down line feeding, four feeding circuit breakers are used: one for each of the up and down lines and directions in the substation. The simultaneous up and down feeding is normally performed by using one of the two circuit breakers for the respective direction. Using the remaining circuit breaker as a backup enhances the reliability of the feeding system.

  - Change-over Section: A change-over section is provided for sections that have different phases to prevent the pantograph from causing short circuit to the different-phase power supplies when a train pass. This is achieved by placing the power supply of a main phase and a teaser phase opposite to each other underneath the substation, and by placing the power supply of different power supply system opposite to each other at the sectioning post. The Shinkansen can operate at a speed exceeding 200 km/h. In order for the Shinkansen to pass while it is powering (without notch control), a middle section of about 1000-m long is constructed to provide two air sections, as shown in the below figure. A change-over circuit breaker is used to adjust the power supply required by the Shinkansen.

The change-over circuit breaker switches upon receipt of a signal indicating the presence or absence of a train. A vacuum-type change-over circuit breaker shall be used. As it switches every time a train passes, a high-frequency specification is required. The vacuum-type change-over circuit breaker is developed for Shinkansen use. Change-over circuit breakers for regular and backup uses will be installed on both the up and down lines to enhance the reliability of the feeding system. The instantaneous switching time is approximately "300±50 ms."



Source: JICA Study Team referring to the previous study (JICA, 2013), etc.

Figure 4.35: Configuration Diagram of a Change-over Section

- Extended feeding: The substation and sectioning post facilities shall have configurations capable of extended feeding. Extended feeding is a method for mainly feeding the same-phase power supply into a regular feeding section when one phase in the substation fails, and for feeding to an adjacent substation through the sectioning post when the adjacent substation suffers power failure. This method ensures the continued supply of power for passenger services, including lighting and air-conditioning, to cars that are still in the section. However, due to the reasons below, extended feeding shall not be used for regular operation.

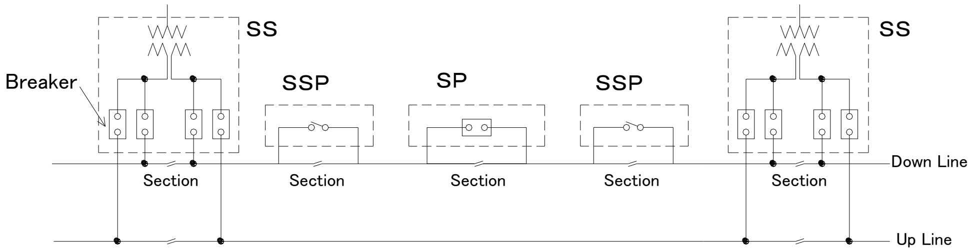
    - ➢ It is unlikely that the power failure at a substation will continue for a long time as two transmission lines will be used for power supply, two feeding transformers will be used for regular and backup operation, and other devices will also have backup.

    - ➢ If extended feeding is used for the purpose of ensuring normal operation, the interval between substations will be longer, and huge facility investment will be needed, making the option very expensive.

    - ➢ Parallel operation of feeding transformers will not be carried out. If it is carried out, then the short circuit current will become very large. It will necessitate raising the current overload capacity of the autotransformer, circuit breaker, and so on, increasing costs. Thus, ratings of the feeding transformers, auto-transformers, circuit breakers, etc., are made on the assumption that regular feeding is used.

- Configuration of the Feeding Circuit

  The below figure shows the configuration of a standard feeding circuit.



Source: JICA Study Team referring to the previous study (JICA, 2013), etc.

Figure 4.36: Configuration of an AC Feeding Circuit

- Voltage Drop in the Feeding Circuit

  Voltage drops in the feeding circuit differ substantially, depending on the conditions of the train position, train current, number of trains in the same power-feeding section, track impedance, etc. Since it is difficult to conduct a detailed review, estimation based on given conditions has been conducted. The result indicates that the minimal pantograph voltage for the train should be 22.5 kV, which is within the tolerable voltage fluctuation range of overhead contact lines.

- Harmonic from the AC Feeding Circuit

  After the Shinkansen train uses a PWM converter to convert the AC power to DC power, the VVVF inverter changes the voltage and frequency to drive the three-phase induction motor. Because the primary current waveform is substantially sinusoidal, there is very little low-order harmonic current. For this reason, the substations do not need to take any measures to tackle low-order harmonic current. Furthermore, since the car interior is designed with features to lower the high-order harmonic current, very little harmonic current can be detected. If, however, there is any concern that the harmonic current generated by the electric trains may interfere with the system, filters and devices can be installed to mitigate the resonance of a harmonic current.

- Coordination of Insulation

  The insulation strength of devices, ranging from the transformers at substations to circuit breakers used in feeding, is basically insulated at BIL 300 kV. Lightning arresters with a rating of 84 kV shall be used. Insulation of BIL 200 kV shall be used for overhead contact lines with autotransformer feeding circuits, change-over switches in change-over sections, and devices in sectioning and sub-sectioning posts. The lightning arresters would be 42 kV rated voltage. A Shinkansen substation has a mixture of extremely high-voltage incoming power, feeding facilities, and low-voltage control circuits. Even though the high-voltage devices have earth fault protection, net-like earth connection is used to distribute the grounding potential evenly. Optical cables shall be used as communication cables for controlling the trains' entry into stations and information display, and as cables for circuit breakers.

- Inductive Interference and Countermeasures

  The communication cables near the overhead contact lines generate induction voltage and noise, which are caused by electrostatic induction proportional to the voltage of the overhead contact line, and by electromagnetic induction induced electromagnetically by the electric current leaked from the return wire to the ground.

- Electrostatic induction: The electrostatic induction voltage induced by the communication lines as a result of the electrostatic induction phenomenon is proportional to the overhead contact line's voltage to the ground. If the overhead contact line contains harmonic voltage, harmonic induction voltage will be generated, which is known as "noise voltage" between railway lines. The following points need to be examined as countermeasures:

  - Separate the communication lines from the overhead contact line as far as possible
  - Enclose the communication lines with cables

- Electromagnetic induction: Electromagnetic induction means that when the overhead contact line in the feeding circuit corresponds to the primary winding of the transformer, and the communication line corresponds to the secondary winding, a transformer circuit is formed. Induction voltage is generated through electromagnetic induction from the overhead contact line to the communication line. The voltage is proportional to the frequency, leakage current, mutual inductance, and length of the parallel sections of the two lines. From the carload, electromagnetic induction voltage will also be generated from the harmonic current if the harmonic current flows to the feeding circuit. This is known as "noise voltage" between lines. The following countermeasures shall be reviewed:

  - Install autotransformers to proactively absorb the current from the rails to harness the current leakage to the ground.
  - Separate the communication line from the overhead contact line as far as possible or cover the communication line with cables.

- Protection Relay System

  - Protection and utilization of power-receiving circuits: Negotiations regarding the protection and utilization of power-receiving circuits shall be held with power utility providers to determine the final system.

  - Protection of feeding transformers: The feeding transformers shall be protected with ratio-operated electrical relays, overcurrent relays, pressure relays, temperature relays, and oil level relays, etc.

  - Protection of feeding circuits: The AC feeding circuits shall be protected with distance relays and ACΔI-shape fault selection devices.

  - Protection of change-over circuit breakers: Because the change-over circuit breakers move frequently, they shall be protected with interelectrode short circuit relays.

- Reclosing of Feeding Circuit Breakers

  During operation of an electric train, if a power outage triggered by an accident on an outside line is lasting for some time, all power sources, including the one to control the electric train, will fail. Using an auxiliary machine to restart the electric train takes time and will cause delay in operations. The AC feeding circuit has relatively frequent occurrences of insulator closed circuits and other one-time accidents. By shutting down the voltage, insulation of the accident point will recover, and feeding will become normal again after the power voltage restarts. The rate of reclosing is also relatively high.

Therefore, this system (reclosing system) is adopted for the Shinkansen system to secure power supply and to enhance the safety of electric train operation.

- Remote Supervision and Control of Substations

  The supervision and control of feeding substations, sectioning posts, sub-sectioning posts, auto-transformer posts, and so on are normally performed from a control center. For data communications between the control center and the substations, etc., a remote supervisory control device equipped with microcomputers, known as SCADA, is used. It is widely used in the power supply systems for Shinkansen and for power utilities in Japan. Its performance is time-proven. SCADA uses a system that allocates the workstations by function, making it possible to provide high-level functions at low cost. It has become the mainstream in today's remote supervision and control environment.

- Configuration of Devices

  - Types of devices used at feeding substations and others: Out-door type devices shall be used for feeding substations and others to standardize equipment.

  - Power-receiving device: Gas-insulated switchgear (GIS) shall be used for the power-receiving devices. GIS has the following characteristics: compact, easy installation and wiring, and safe because no charging part is exposed. Power is received from the utility company via two lines. Each line is connected directly to a feeding transformer. Because there is no parallel charging, the circuit configuration is simple. One line is for regular use, and the other is a backup line. The operation will automatically switch to the backup line if primary line failure occurs.

  - Feeding transformer: The Roof Bridge connection transformer shall be used as the feeding transformer. Two transformers shall be used, one for regular use and the other for backup. No simultaneous operation will be carried out.

  - Feeding device: To keep the installation area small, construction cost low, and to ensure safety, a gas-insulated switchgear (same as the one used for receiving power) shall be used as the feeding transformer's main circuit device for secondary feeding. Two units of the feeding circuit breaker shall be installed in each direction, one for regular operation and the other for backup operation. This offers an extremely reliable device configuration. When one unit fails, the connection will shut down automatically and switch to the backup unit to ensure normal feeding. The change-over circuit breaker for the change-over section will also have one for regular operation and one backup to enhance reliability.

  - Distribution cubicle: The distribution cubicle, which safeguards supervisory control, uses the programmable controller (PC), digital relay (PI), and other devices designed for microcomputer applications so that it will be compact in size and maintenance-free. PC and PI shall have a duplex configuration to enhance reliability. Besides performing the ordinary supervisory control functions, the PC also has measurement, automatic change-over, reclosing, and other functions built-in. Since devices designed for microcomputer use shall be used, air-conditioners shall be installed at buildings that have distribution cubicles.

  - Redundancy of devices: As described above, the main devices, including power-receiving devices, feeding transformers, feeding circuit breakers, and change-over switchgear, all have duplex designs, making the configuration very reliable.

- Sectioning post, sub-sectioning post, AT-post, and sectioning disconnector: The main circuit devices for the sectioning posts and others shall be configured around the gas-insulated switchgear (GIS), similar to ones used at feeding substations, to achieve more compact configurations. The distribution cubicle will also use PC and PI as at the substations to reduce size. These distribution cubicles shall be installed under the elevated tracks to reduce land acquisition cost.

vi) Calculation of Capacity of Substation Equipment

- Feeding circuit

  Based on the configuration of the feeding circuit described above.

- Train-set

  Two types of train-sets are assumed.

  - Number of Trains : Hanoi – Vinh 4 trains/hour/direction
    : Nha Trang – Thu Thiem 5 trains/hour/direction
    : Hanoi – Thu Thiem 5 trains/hour/direction
  - Max Train Speed : 320 km/h
  - Train Set : 10 cars (8M2T)
    : 16 cars (14M2T)
  - Weight of Train : 10 cars 500 tons
    : 16 cars 800 tons
  - Load Power Factor : 0.99
  - 1-hour average current : 10 cars 470 A
    : 16 cars 754 A
  - Voltage at Pantograph : 25 kV 50 Hz
  - Transmission Voltage : 30 kV
  - Power Transmitting Distance : 40 km

vii) Capacity of the transformer for power supply

- Standard Transformer

  The standard capacity of the transformer is as follows.

Table 4.33: Standard Transformer

Type	Capacity (kVA)
Modified Woodbridge	50,000, 80,000, 100,000
Scott connection	10,000, 15,000, 20,000, 30,000, 50,000, 80,000, 100,000

Source: Standards for design and construction of electrical equipment (JRCC, 1988)

The reliability of the feeding transformer is improved by increasing the overload rated capacity, considering the following matters:

- The load of the electric vehicle fluctuates greatly.
- The transformer capacity and the maximum hourly electric power estimated through average electricity consumption rate is balanced.
- Consideration of momentary maximum power.
- The overload-rating shall be repeatable "300%, 2 minutes" continuously.

- Power Transmitting Distance

  The power transmitting distance (distance between substations) shall be determined through site surveys and power grid planning in the future.

- Maximum Power Output per hour

  The mean power consumption ratio of one train can be calculated by the following equation:

<10 cars, 4 trains/hour/direction>
The Shinkansen's average power consumption rate Pm is 50 kwh / 1,000t-km.
The one-hour maximum power is calculated by the following equation:
$P = P_m \times W_t \times D \times N = (50 \times 500 \times 40 \times 8) / 1,000 = 8,000$ kwh
P: one-hour maximum power (kwh)
P_m: mean power consumption ratio (50 kwh/1,000t-km)
W_t: Weight of train 500 ton
D: Power transmitting Distance (40 km)
N: number of trains per hour (8 train/hour/both directions)

$KVA = P \times \alpha \times \beta \times \gamma / \delta = 8,000 \times 1.5 \times 1.2 \times 1.515/0.99=22,036$
α Extended power supply: 1.5
β Future load increase: 1.2
γ Future Speed Increase: 1.5
δ Power Consumption ratio: 0.99

Adding A) connection power source circuit and B) connection power circuit
22,036+22,036=44,072KVA=44MVA
Therefore, the transformer capacity is 50 MVA from the above information

<10 cars, 5 trains/hour/direction>
As the transformer capacity is 25 % larger ((5-4)/4=0.25) than 4 trains/both directions,
44MVA × 1.25=55MVA
The transformer capacity is 80MVA from the above information.

<16 cars, 5 trains/hour/direction>
As the transformer capacity is 1.6 times of 10 cars ((16-10)/10=1.6),
55MVA × 1.25=88MVA
The transformer capacity is 100 MVA from the above information.

- Estimated capacity

  The estimated capacity is shown in the next table.

Table 4.34: Estimated and Rated Capacity

Section	Number of Trains (one way)	One-hour Maximum Power (MW)	Capacity of Transformer (MW)	Note
Hanoi – Vinh	4 trainsets of 10 cars, (1 express and 3 local trains)	44MVA	50MVA	40 km Power transmitting Distance
Nha Trang – Thu Thiem	5 trainsets of 10 cars, (1 express and 4 local trains)	55MVA	80MVA	
Hanoi – Thu Thiem	5 trainsets of 16 cars, (5 trains)	88MVA	100MVA	

Source: JICA Study Team

It is desirable to decide on the capacity of transformer needed by considering the timing when the operation of 16-car trains will begin. If 16-car train operations begin 25-30 years after the start of business, it is reasonable to initially set up an 80 MVA transformer and upgrade to 100 MVA later on because this timing will coincide with the time to update other equipment anyways.

However, if 16-car train operations begin within 10 years from the start of business, it is better to set 100 MVA from the beginning. The difference of transformer cost between 80 MVA and 100 MVA is around 5% of the total construction cost, and renewal under train operation is very expensive.

- The capacity of Automatic Transformer (AT)

The capacity of AT is decided from taking the larger of the short-circuit current and load current.

The self-capacity of AT is the product of the voltage and current of series winding or common winding; it indicates the substantial electrical energy. The line capacity means the supply capacity, and it is twice as much as the self-capacity when the turn ratio is 1:1.

- Short Circuit Capacity

The short circuit strength is obtained from the short-circuit current I_s at the place where the AT is installed. If the feeding voltage is V, and the short-circuit current is N, the short circuit capacity W_1 (self-capacity) is obtained from the following equation:

$W_1 = (V/I_s) / (2N)$

W_1: Short-circuit capacity (self-capacity)
V: Feeding voltage
I_s: Short-circuit current at the place
N: Short circuit current

The short circuit strength is generally 25 times (25x), but when the short-circuit current of the substation is large, it can increase to 35 times (35x). Since the short-circuit current has not been calculated, the calculation of this formula has been omitted.

- One-hour maximum capacity

The one-hour maximum power is expressed by the following equation:

$W_2 = (P_m WNL) / (2P_f) = (594*588*5*10) / (2*0.99) / 1,000$
$= 17,463 / 1.98 = 8,820$

W_2: One-hour maximum power (train's power consumption rate)
P_m: Average power consumption rate (kwh/1,000t-km)
W: Train weight (t)
N: Number of trains
L: Distance between AT (km)
P_f: Load power factor 0.99

Note: The reason why the figure is divided into two in the formula is because two trains are between two ATs.
Therefore, the AT capacity is calculated as 10 MVA.

Table 4.35: Standard Capacity and Short Circuit Strength of Automatic Transformer

Transformer Connection	Capacity (KVA)	Short-circuit Capacity
Auto-transformer	5,000, 7,500, 10,000	25 or 35

Source: Standards for design and construction of electrical equipment (JRCC, 1988)

viii) Transforming Devices for Civil Engineering Structures

- Commission of Civil Engineering Works

  The following civil engineering works shall be commissioned:
  - Land acquisition for substations
  - Land development for substations
  - Drainage works for station premise
  - Access roads to substations
  - Piling for construction
  - These details shall be discussed with the civil engineering team in the design phase.

- Commission of Construction Works

  The following construction works shall be commissioned:
  - Drainage for station premise
  - Roads on station premise
  - Perimeter walls
  - Buildings
  - Water supply and drainage facilities
  - Fences, doors, and gates
  - The details shall be discussed with the construction team in the design phase.

2) Overhead Contact Line Facility

i) Overhead Contact Line Facility Plan

An overhead contact line facility's purpose is to supply power to electric trains from a substation through a pantograph. It consists of; feeding contact line, overhead contact line, protection devices, and various support, etc. Because the overhead contact line must supply stable power to electric trains constantly and is a single-system facility, it must be a very safe facility.

ii) Basic Specifications

- Electric System and Feeding System
  - Electric system: Single-phase AC 25,000 kV and frequency of 50 Hz shall be adopted.
  - Feeding system: AT feeding system shall be adopted.

- Weather Conditions

  The following weather conditions are assumed:

  - Temperature: Past temperature data of Vietnam are used as the assumed temperature for design purpose.

- Wind: The maximum instantaneous wind speed of Vietnam in the past is used as the assumed wind speed for design purpose.
- Lightning: Lightning measures are planned for all regions of Vietnam.

• Messenger Wire System

The below table shows the suspension system of the overhead contact line, types of electric cars, and standard tension.

Table 4.36: Types of Overhead Contact Line and Standard Tension

Section	Suspension system	Kind and Sectional Area		Standard Tension
Main line	Simple catenary suspension system CS simple (tension 4.0 t) (39.2 kN)	Messenger wire	Hard drawn copper wire strands 150 mm^2	2,000 kgf (19.6 kN)
		Contact wire	CS contact wire 110 mm^2	2,000 kgf (19.6 kN)
Lines other than mainline	Heavy simple catenary suspension system (tension 2.5 t) (24.5 KN)	Messenger wire	Zinc-coated steel wire strands 110 mm^2	1,500 kgf (14.7 kN)
		Contact wire	Grooved hard copper contact wire 170 mm^2	1,000 kgf (9.8 kN)

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

• System Height

The below table shows the system height of the overhead contact lines.

Table 4.37: Standard Height of Overhead Contact Lines

Suspension System	Section	System height
Simple catenary suspension system	All sections	950 mm
Heavy simple catenary suspension system	Station premises	950 mm
Heavy compound catenary suspension system	All sections	1,500 mm

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

• Contact Wire Height Gradient

The contact wire height of the mainline shall be 5,000 mm ± 100 mm. The gradient of the mainline and the contact wire shall be 1/1,000 or less.

• Steady Arm

The contact wires of a straight line and a curved line of 12,000 m or more are equipped with steady arms, as shown in below table.

Table 4.38: Installation Range of Steady Arm

Section	Installation Range	Remarks
Open section	Each supporting point	A steady arm is also installed at the first supporting point of a tunnel entrance.
Tunnel section	Every 4 spans	

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

The contact wire of a curve line less than 12,000 m is equipped with a pull-off arm, as shown in below table.

Table 4.39: Range of Pull-off Arm

Section	Installation range	Place
Open section	All locations	At each supporting point
Tunnel section	10,000 m ≤ R ≤ 12,000 m	Every 2 spans
	R<10,000 m	At each supporting point

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

- Tensioning System

The length of the termination anchor of the overhead contact line shall be 1,600 m or less. Automatic tensioner and manual tensioner will be installed at overhead contact lines.

- Feeder

The below table shows the types of feeders.

Table 4.40: Kind and Standard Tension of Feeder

Section	Kind of wire
Overhead type, Open section	Hard aluminum wire strands 300 mm^2 Hard copper wire strands 200 mm^2
Overhead type, Open section (Salt damage section)	Hard copper wire strands 200 mm^2
Tunnel section	Hard copper wire strands 200 mm^2
Ground-type	Crosslinked polyethylene insulated vinyl sheath cable 200 to 600 mm^2

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

- Protection System

Below table shows the application sections of various protection systems.

Table 4.41: Application Sections of Various Protection Systems

Protection system	Application section
AT protective wire discharge gap system	Ordinary open sections
AT protective wire discharge gap system	Tunnels
Ground wire for flashover system (FW system)	Tunnels (not subject to influence of direct current)
Contact line protection system	Feeder lead steel trench
Independent grounding system	Disconnecting switch, devices such as line transformer, etc.

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

The below table shows the types of protective wires.

Table 4.42: Types of Protective Wires

Section	Kind of wire
Open section	Hard aluminum wire strands 150 mm^2 Hard copper wire strands 75 mm^2
Tunnel section	Hard copper wire strands 75 mm^2

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

- Distance between Supports

  The overhead contact line support spans shall be based on the below table. The standard for the difference between adjacent spans shall be 10 m or less. Only in cases of absolute necessity can the difference be 15 m or less.

Table 4.43: Standard Spans

Section	Standard span
Open section	50 m
Tunnel sections	45 m

Source: JICA Study Team based on "Kyushu Shinkansen Construction Reports: Hakata - Shinyatsushiro" (JRTT, 2012)

- Overhead Contact Line Supports, Insulator
  - Pole: Pole types shall be steel pipe mast and steel poles.
  - Fixed beam: An angle steel squirrel-cage beam and a V trussed beam shall be the standard for the fixed beam.
  - Hinged cantilever: Hinged cantilevers shall be used to support the overhead contact line.
  - Drop arm: Steel pipe drop arms shall be the standard for tunnel supports.
  - Insulator: Suspension insulators shall be used for overhead contact wires, and long rod insulators shall be used for hinged cantilevers.

- Switchgear

  Locations that need sectioning, such as station sidings and car depots, shall be equipped with switchgear. The switchgear shall be lockable at each of the open, close, and grounding positions. The switchgear shall only be operated by authorized personnel.

- Rail Bond

  Rail bonds shall be installed at branching and EJ (rail expansion joints) locations.

iii) Civil Engineering Structure-related Overhead Contact Line Facilities

The following overhead contact line facilities shall be constructed in conjunction with civil engineering structures: foundation of electric poles, foundation of branch lines, facilities inside tunnels (drop arm, siding, material borehole, etc.), grounding, and various crossing pipelines etc. The details shall be discussed with the civil engineering team in the design phase.

3) Electrical Facilities for Lighting

i) Electrical Facilities for Lighting

- Overview of Facilities: Electrical facilities for lighting differ substantially depending on whether the electrical facilities are for supplying electricity to load other than the Shinkansen rolling stock, or load facilities such as lighting and electrical outlets at station buildings. Electrical facilities refer to the distribution points that receive electricity from utility companies and allocate the electricity to various loads, the distribution line facilities that distribute the allocated electricity to various loads, and lighting facilities (load facilities). Lighting facilities include the facilities inside tunnels, electrical outlet facilities for maintenance use, facilities on station and car depot premises, and building facilities, etc. Building facilities are not included because they are not unique to railway.

- Basics of System Specifications: Since the HSR electrical facilities do not have special systems or mechanical equipment, they shall be configured in the same way as the ones used for conventional electric railways, utility companies, and large power users. However, because it is necessary to coordinate the reliability of power supply with other systems, duplex power supply (double lines) shall be used for all facilities directly related to train operation and related load facilities. Furthermore, because the reliability of power supply differs depending on the power-receiving locations, emergency power generators shall be installed to ensure the reliability of power supply.

ii) System Contents

- Distribution Point Facility
  - Distribution points are constructed at stations, workshops, and car depots. A distribution point receives a high-voltage or especially high-voltage power from the utility company via a single line. It then converts the power into a predetermined power supply and distributes it to each facility on the station premise and to the trackside.
  - Emergency power generators shall be installed as a measure to prevent service interruption of power supply from the utility company.
  - All distribution point equipment shall be installed indoors.
  - The equipment is remotely monitored and controlled from the control center. The system also includes the substation remote supervisory control system.
  - An indoor electrical room shall be set up at each load point as the lower power supply facility of the distribution point. Double lines (the primary system and backup system) shall be used to supply power to the electrical room.
  - The condition of the equipment in the electrical room is monitored from the power control center via substation remote supervisory control. A simple remote monitoring device shall be set up with the distribution point as the main station and the electrical room as the substation.
  - UPS shall be installed at the stations and control center as a measure to cope with instantaneous service interruption of the power supply.

- Distribution Line
  - A single (or double in sections that supply power to long tunnels) high-voltage distribution line (three-phase 6.6 kV power cable) shall be installed to supply power to facilities between stations.
  - Power cables in an open section shall be attached to cable duct through civil engineering construction, and the power cables in a tunnel section shall be attached to the side of the walls.
  - The high-voltage cable is branched out midway from the mainline to supply power to maintenance depots between stations, signal communication equipment rooms, and substations, etc.
  - The electric room for an intermediate signal equipment room is monitored and controlled from the power control center via the substation remote supervisory control. A simple remote monitoring device shall be installed using a station distribution point as the main station, and the electrical room as the substation.
  - Low-voltage power shall be supplied to other load facilities from an outdoor power supply facility. One is set up at every kilometer throughout the entire line.

- Tunnel Lighting Facility
  - Tunnel lighting is provided for tunnels over 200 m in length. One power supply shall be installed in the tunnel's material borehole at every kilometer.
  - Lighting averaging 5 lux (installed on the sidewalls of the up and down lines at 15-m intervals) shall be used to provide lighting bright enough for walking.
  - One section of the on/off tunnel illumination shall be set at 1 km. The on/off switches are installed at 500-m intervals.
  - In addition to the on/off switches mentioned above, switches for lighting the entire tunnel during emergency situations shall be installed at 500-m intervals (where the telephones are located). This lighting function can be controlled from the power control center via the substation remote monitoring device. A simple remote device shall be installed using the distribution point as the main station, and the tunnel as the substation.

- Electrical Outlets for Maintenance Work
  - Electrical outlets for maintenance work shall be installed at 100-m intervals on one side of the track throughout the entire line.
  - The power supply shall be installed at 1-km intervals on the viaducts or under the viaducts, and in the tunnel's material boreholes. The power shall be supplied to the outlets using low-voltage cables.
  - The low-voltage cables and ground wires in open sections shall be installed in cable ducts. The high-voltage cables and low-voltage cables are separated by incombustible partition walls.

- Facilities in Car Depots and Workshops
  - A high-voltage distribution line (three-phase 6.6 kV) is used to supply power from the distribution point to the loads distributed in the yard. Double high-voltage distribution lines are used, one for the primary load and one for the backup load.

- Low-voltage power is supplied from an outdoor power supply facility to loads installed outdoors and to small-scale buildings.
- The outdoor power-supply facility shall be housed in outdoor cubicles. It shall be configured with a transformer and a circuit breaker for low-voltage distribution lines.
- Floodlights from the overhead contact line support are used as the standard illumination for the yards to ensure safety.
- An overhead contact line pressure indicator shall be fitted with an arrival/departure identification indicator, and other equipment needed for safety reasons.

iii) Standards for Various Systems

- Facilities at Distribution Points

  The standard voltage of power received at the distribution point is three-phase 50 Hz 6.6 kV.

  - The standard for high-voltage circuit breakers is the vacuum-type circuit breaker.
  - The mold-type transformer shall be used.
  - Boards that house the circuit breakers, transformers, and other electrical devices shall be placed in metal-clad drawers. The standard for protection relay is IP2X.
  - The circuit breaker for protecting the transformers shall use LBS for 300 kVA and below. It shall be housed in a transformer board.
  - Reactor and discharge coil shall be added to the condenser for power factor improvement.
  - Gas turbine generators shall be used as emergency power generators. The generators shall be housed in rooms at designated sections.
  - Kerosene will be the standard fuel. The storage amount shall be enough to supply 10 hours of power.
  - The devices for protection, measurement, and control shall be the static types.
  - Remote supervisory control devices shall be based on the remote supervisory control devices used at substations.
  - For low-voltage circuit breakers, the secondary circuit breakers, ACB shall be used for circuit breakers with transformer capacity over 500 kVA, and MCCB for others.
  - MSE type shall be used for the DC electrical device for equipment control.
  - Wiring and cables at the distribution point should be fireproof and nonflammable, or the non-toxic materials that put out a little smoke even when caught on fire.
  - The specifications of equipment in the low-order electrical rooms at distribution points shall conform to those used at the distribution points.

- Distribution Line Facility

  - The high-voltage distribution lines shall use 3-phase 6.6 kV, and the cables shall use 6 k-CVT. Non-toxic materials that only give out a small amount of smoke when caught on fire shall be used inside tunnels.

- The specifications of power equipment that are used between stations shall conform to the specifications of equipment used at distribution points.
- The transformer of power equipment, which are installed at 1-km intervals, shall be 3-phase 6.6 kV/240 V, with 30 kVA neutral grounding, and stored in a corrosion-proof box. The protection equipment is PC.

• Tunnel Lighting

- The tunnel lighting shall use corrosion-proof lights, which shall be installed at 15-m intervals on both sides of the tunnel.
- Branch cables shall be used as low-voltage cables for lights and electrical outlets inside tunnels. They shall be installed along the side walls. Non-toxic materials that only give out small amount of smoke when caught on fire shall be used for cables.

• Electrical Outlets for Maintenance Works

- The electrical outlets for maintenance works shall be installed inside a corrosion-proof box to prevent earth leakage. There shall be two 3-phase 240 V outlets outfitted with grounding terminals. The box shall be installed at 100-m intervals along the tracks, on sound-proof walls, or electric poles.
- The distribution cables for outlets shall use plastic branch cables, and the grounding lines shall use plastic wires. They shall be enclosed in cable ducts.

iv) Electrical Facilities for Civil Engineering Structures

• Cable Duct: Cable ducts shall be constructed on one side of the track along the open sections (on both sides of the section that has distribution lines in long tunnels) to store cables.

• Material Boreholes inside Tunnels: Boreholes shall be constructed at 1-km intervals on one side of the tunnel (on both sides if the tunnel is long) to store materials such as transformers that supply electricity to tunnel lighting and other fixtures inside tunnels. The boreholes shall also be used for signal and communication equipment.

• Grounding: Each material borehole shall have earth grounding connections for electrical use inside tunnels. The C-type, D-type, and an auxiliary grounding for measuring the other two earth connections shall be used. The resistance value specified at construction is set at about 80%, taking seasonal fluctuations into consideration. However, when various types of earth connections are used, the ground resistance shall be at 10 ohm or less.

• Track Crossing Pipe Lines: Cable-storing pipes that cross tracks shall be buried underground. Polyester flexible conduits (FEP) shall be used because they do not corrode and are flexible.

(3) Power Distribution Line of Shinkansen

1) Introduction

When the Tokaido Shinkansen opened in 1964, JNR did not own a distribution line, and each facility such as signal and lightning received electricity from electric power companies. As a result, there were problems with the train operation when the electric companies failed supplying electricity. As a countermeasure, JNR equipped an electric room at each station from which JNR installed the 6.6 kV distribution line dedicated to the Shinkansen after construction of the Tohoku Shinkansen.

In 1972, a train fire accident occurred in the tunnel of the Hokuriku main line, and 137 people died. There was no lighting equipment in the tunnel at the time, which was one factor that impeded the evacuation of passengers. From this unfortunate incident, installation of lighting equipment in the tunnel became mandatory. In addition, long tunnels of 5 km or more were required to install "lighting that lights up entire tunnel when activated" which receives electric power from two separate lines. Later, the Tokaido Shinkansen installed its own distribution line of 6.6 kV from electric rooms at the stations.

2) Power supply from a dedicated power distribution line

From the distribution line of the Shinkansen, electricity is supplied to the following components:

- Lighting equipment in the tunnel
- Outlet box for maintenance installed along the railway line
- Train protection switch of Shinkansen
- Train approach warning system in the tunnel
- Charging device for maintenance car
- Wireless hut
- Equipment for amplification of LCX
- Rain gauge, anemometer, seismograph
- Power supply for manipulating and/or remote control of the disconnecting switch
- Standby power supply for substation, sectioning post. Auxiliary sectioning post
- Signal equipment
- Others

3) The voltage of the distribution line

- Regulation of voltage in Japan

In Japan, Article 2 of the electrical equipment technical standard describes voltage as follows;

Table 4.44: Electrical Equipment Technical Standard (Article 2)

Classification	Note
Low voltage	750 V or less for DC and 600 V or less for AC
High voltage	more than 750 V and less than 7,000 V for DC, and more than 600 V and less than 7,000 V for AC
Special high-voltage	more than 7,000 V for both AC and DC The Institute of Electrical Engineers for special high pressure in Japan defines 22 kV, 33 kV, 66 kV, 77 kV, 154 kV, 275 kV, 500 kV, 1,000 kV as standard.

Source: Technical Standards of Electrical Equipment (Ministry of Economy, Trade, and Industry, 2013)

- The voltage of distribution lines of conventional railway in Japan

All railway companies in Japan apply 6.6 kV. In addition, the power distribution voltage of the power companies is also 6.6 kV.

- Equipment to receive electricity from the distribution line of the conventional line.

The following table shows the equipment that receives electricity from the distribution line.

Table 4.45: Equipment that Receives Electricity

Equipment	Examples
Power supply	Snowmachine, Pump, Railway crossing, Lighting
Signal	Turnout, signal light, track circuit, railway crossing (crossing gate, track circuit)
Communication	Telephone, Router, Transceiver

Source: JICA Study Team referring to the records of Shinkansen construction by JRTT

- The voltage of power distribution lines overseas

The next table shows the power distribution lines around Asia.

Table 4.46: Equipment that Receives Electricity

Nation	Line	Voltage kV	Object
Indonesia	Conventional	6.6	signal lights, railroad crossing power supplies, etc.
Thailand	Conventional	6.6	
Taiwan	High-Speed	6.6	Same with Shinkansen
China	High-Speed	6.6 & 10.0	

Source: JICA Study Team hearing from experienced electrical engineers

4) Comparison of 6.6 kV and 20 kV

i) General comparison

The next table outlines the general comparison between 6.6 kV and 20 kV.

Table 4.47: General Comparison between 6.6 kV and 20 kV

kV	Danger	Machinery			Cable				Note
		Insulation	Frame size	cost	Size	Cost	Space	Work	
6.6	1	1	small	1	1	1	1	Easy	○
22	3	2	big	4	0.5	2	2	Hard	▼

Source: JICA Study Team referring to the records of Shinkansen construction by JRTT

ii) Machinery

The equipment becomes bigger as the voltage increases. This is because of the necessity of more insulation between cable and frame, and between cables. Therefore, the size becomes large, and the price rises. Subsequently, construction cost rises, and it is necessary to obtain a larger site.

iii) Cable

When the voltage increases, the cables become thinner, and the distribution distance can be lengthened. However, the cost of the cable increases. The difference in installation cost is not much different as it is installed by machine. The high voltage cables require a large separation distance. For terminal processing of cables, special qualified persons are required, and material expenses and construction costs increase. In the case of 6.6 kV, it is possible for general electric craftsmen to construct. Therefore, material costs and construction costs can be reduced.

iv) Influence on the construction cost of viaduct and tunnel

The size of the switchboard influences the width of the viaduct. In case of the Taiwan HSR, 6.6 kV panel board (transformer box) was set on the viaduct, but if it was 22 kV, it would not fit within the formation width. In addition to the construction cost of viaducts, land acquisition also increases.

v) The equipment inside the tunnel

Inside the tunnel, lateral holes are required for the installation of switchboards. In the case of 22 kV, it will be a large switchboard, and lateral holes become larger, increasing the tunnel construction cost.

vi) Equipment Maintenance

Equipment compatible with special high pressure is large, and there is no choice but to put it under the elevated structure. Therefore, it is necessary to secure an access route for maintaining the equipment. If it is compatible with 6.6 kV, it can be put on the viaduct, making maintenance easier.

5) Conclusion

In overall consideration, the distribution line voltage of 6.6 kV for the Vietnam HSR is recommended, considering the level of safety, board size, price, cable construction method, maintenance, etc.

4.3 Signaling and Communication

4.3.1 Purpose and Function of Railway Signal

The purpose of the 'railway signal' is to enable safe operation of multiple trains operating on the track. The functions are "Blocking," "Speed Controlling," and "Interlocking."

1) “Blocking”

The principle of “Blocking” is that only one train shall occupy a certain section. It enables avoiding collisions between trains.

"Blocking" includes a "fixed blocking" method in which the section is fixed and a "moving blocking" method in which the section moves according to the position of the train.

The former has a disadvantage of lowering the line capacity by occupying a longer blocking section for a high-speed train with a long brake distance.

On the other hand, the latter can minimize the distance between the trains, so it contributes to both high-speed operation and securing of line capacity.

However, it is indispensable for the "moving blocking" method to grasp the current position, speed, direction of travel, and performance of each train in real-time, and to transmit the information by the radio device.

2) “Speed Controlling”

With "Speed Controlling," the train’s speed and direction can be regulated by the system for added safety.

The train operator can secure safely operate the train according to signals, i.e. ("green: proceed," "yellow: proceed with caution," "red: stop") or "permissible speed,” i.e. (xx km / h or less"). However, if a human error such as misidentification or oversight of the signal occurs, it may cause serious train accidents such as collision, derailment, etc.

Therefore, the modern railway is equipped with an automatic train control device, i.e., ATS (Automatic Train Stop device) or ATC (Automatic Train Control device), having the ability to automatically engage the brakes, decelerate or stop the train, when the train's speed surpasses the threshold from human error.

As a system in which a train receives a "speed control" signal from the ground, there are two methods, "discrete reception" and "continuous reception." The former method receives signal discontinuously from multiple points. The latter method receives a signal via track circuit or radio. High-speed railways normally adopt the latter method to achieve both high-speed and efficiency.

3) “Interlocking.”

By "interlocking," the course of the train is safely constructed.

Through “interlocking,” safe routes are set up, even in the complicated rail network of a station yard.

In the early days of railways, signalmen or station masters were responsible for ensuring the safety of route before allowing a train to proceed into the section. If they make mistakes of their handling, it led to accidents, sometimes with fatalities.

The "interlocking" was introduced as signaling equipment to connect the operation of mutually related devices, such as turnouts and signals, and the train's location. The "interlocking" is the fundamental mechanism that ensures other trains shall never enter on the same route where the train is on or in the direction of progress.

The above "Blocking," "Speed Control," and "Interlocking" were not introduced in the founding era of railways. These concepts have been innovated through the culmination of lessons learned from numerous serious train accidents that occurred over many years, and the excursion of high-speed and high-density railway operation.

4.3.2 Study on the Signaling System in Vietnam HSR

(1) The Signaling System of the Tokaido Shinkansen

1) The Signaling System of the Conventional Railway

The signaling system of the ordinary conventional railway adopts a "fixed blocking" method that automatically detects the train position by a track circuit for "Blocking," with the assistance of an interlocking device at each station for "Interlocking." "Speed Controlling" is independent via a wayside signal placed on the boundary of the track circuit, and indicates the driving conditions to the train driver which complements wayside signals.

There is abundant information on the safe driving of trains, as shown below. Most of the conventional railways mainly rely on the operation plan and the driver's discretion. Many lines limit the train speed to less than 120 km/h so that the trains can stop in a braking distance of 600 meters, which is regarded as the normal boundary of the driver's viewing distance.

Table 4.48: Necessary Information on Safe Driving

Type of Information			Actual Cases
1)	Guideway	plan	Speed limit (curve, gradient, turnout, ground condition, feeding boundary, under maintenance work, etc.)
		site	Rail displacement/breakage, trackbed deformation/collapse, fallen tree, abnormal overhead catenary wire, fire nearby, etc.
2)	Operating condition	plan	Departure/arrival/transit time, starting order from the station, vehicle/crew operation method, vehicle cleaning, etc.
		site	Signal aspect (Route setting, train separation), intrusion into level crossing, in-track limiting troubles (including interruptions), etc.
3)	Weather	site	Strong wind, heavy rain, lightning strikes, flooding, earthquakes, rail temperature rising, etc.
4)	Vehicle condition	plan	Acceleration/deceleration performance, energy efficiency, product empty load limit, vehicle kilometer, inspection interval, etc.
		site	Axle breakage, running trouble, instrument failures (brake, door, pantograph), etc.

Source: JICA Study Team

2) The Signaling System in the Tokaido Shinkansen

When the Tokaido Shinkansen between Tokyo and Shin-Osaka (515 km) opened in 1964, the fastest train "HIKARI" was scheduled to run in 3 hours and 10 minutes and to stop at only two stations in Nagoya and Kyoto on the way.

The braking distance at the maximum speed of 210 km/h to stop was about 3 km, which greatly exceeds the driver's ability to see. It means that "speed control" by the human eye is impossible to secure the safety of high-speed trains.

For this reason, on the Tokaido Shinkansen, the "Blocking" and "Interlocking" followed the conventional railway style, but for "Speed Controlling," ATC was introduced which automatically decelerates the train following the signal transmitted from the ground.

Also, the Tokaido Shinkansen was newly equipped with various fully automatic and centralized systems. At the same time, to improve the command management tasks, the directives such as transportation, passenger, facilities, electric power, signal communication, etc., were consolidated in the Central Control Office at the Tokyo station.

Table 4.49: Modernization of Transport Policies on the Tokaido Shinkansen

Policy	Specific Contents
Automatic detection/ warning for track disorder	With dedicated overpass/underpasses, there are no railway crossings with roads. Also, the automatic detecting and warning system for track disorders is installed for additional safety.
Automatic Train Control System	As a standard safety precaution, speed signal type ATC (Automatic Train Control) system is installed. The ATC system consists of the ground equipment installed at each signal house and along the wayside, and the onboard equipment mounted on each train. The signal receiver of the track circuit performs the train interval control for the automatic train control device (ATC) capable of constantly detecting a train while concentrically controlling the receiving level in each track circuit. The onboard device compares the received ATC speed signal with the current speed. If the current speed is more than the limit speed provided, the onboard device engages the brakes, and if the speed is less than the limit, the brakes are released. In the case of ATC system failure, a backup security system which allows only one train between stations using the train counter device is activated.
Traffic & Power Management System	The CTC (Centralized Traffic Control) system, Train Radio system, and CIC (Centralized Information Control) system are installed. With these systems, operation monitoring for high-speed trains, route control for each station, and direct mutual communication between crew and operational commander are performed. The Centralized Substation Control (CSC) system is installed to centrally control the monitoring and change of feeding system by central command.
Train Protection System	In case of abnormality, train protection devices such as train protection switch, train protection radio device and device for clearance disorder alarm are provided for forcibly stopping the train, as a practical means.
Maintenance Working Protection System	In principle, the time zone of train operation (6:00-24:00) and maintenance hours (0:00-6:00) are separated, and the safety for both are guaranteed. At the end of the maintenance work period, a confirmation car is operated on all sections of the line to eliminate the risk of infringing track clearance for the first train.

Source: JICA Study Team

3) Improvement of Transportation Capacity on the Tokaido Shinkansen

During the 54 years after the opening of the Tokaido Shinkansen, there have been many improvements as shown in the table below for further high-speed / high-density operation.

Table 4.50: Advancement of Transport Capacity on the Tokaido Shinkansen

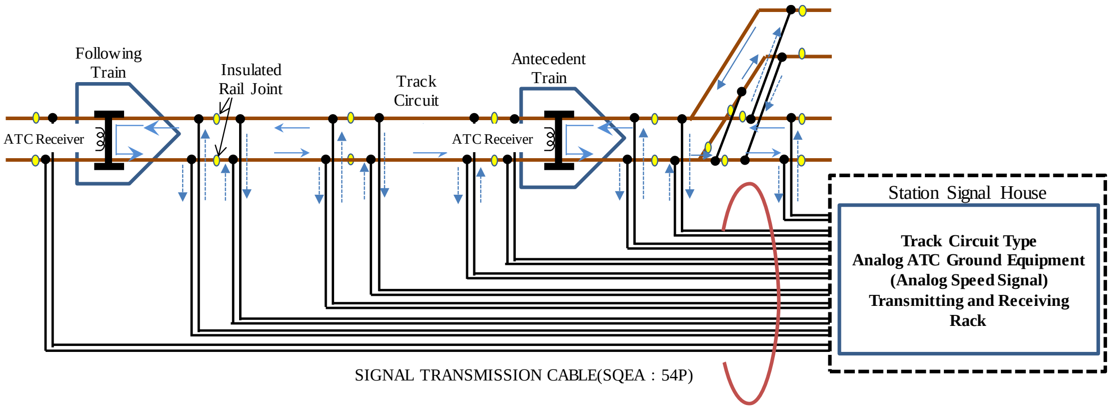
Item	1964 (opening year)	2018
Series	Series 0	Series N700 (A)
Train weight	672 tones/12-car trainset	700 tones/16-car trainset
Maximum speed	210 km/h	285 km/h
Starting acceleration	1.0 km/h/s	2.6 km/h/s
deceleration (ordinary)	2.84 km/h/s	2.70 km/h/s
Rated traction motor	185 kW DC series motor	305 kW Squirrel-cage induction motor
Total output	8,880 kW (12M), 11,840 kW (16M)	17,080 kW (14M2T)
Minimum travel time	3 hours and 10 minutes (stopping in Nagoya and Kyoto)	2 hours and 22 minutes (stopping in Shinagawa, Shin-Yokohama, Nagoya, and Kyoto)
Passenger capacity	987 (12-car), 1,340 (16-car)	1,323 (16-car)
Trains/day	86 [2 (Hikari)-2 (Kodama) pattern/hour]	365 [10 (Nozomi)-2 (Hikari)-2 (Kodama) pattern/hour]
Passengers (1,000)/day	84 (1965)	452
ATC	Analog type, single-frequency, power-synchronous SSB modulation (multi-stage braking)	Digital type, ATC-NS (single-stage braking)
Train radio	Space-wave, analog type	LCX (*1), digital type
Number of channels	8-analog channel (only voice circuit)	42-digital channel (voice/data circuit including Internet access)
Callable area	Over 99.9% of all lines	Over 99.99% of all lines
SN (*2) ratio	Over 35 dB over 90% of all lines	Over 40 dB over 99% of all lines
Bit error rate	N.A.	SN: Signal to Noise (*2) Under 1×10^-4

(*1) LCX: Leaky coaxial cable, (*2) SN: Signal to Noise
Source: Tetsudo Yoran (MLIT, 2018), Shinkansen 50 years history (Kotsu Kyouryokukai, 2015)

4) Digitalization of ATC on the Tokaido Shinkansen

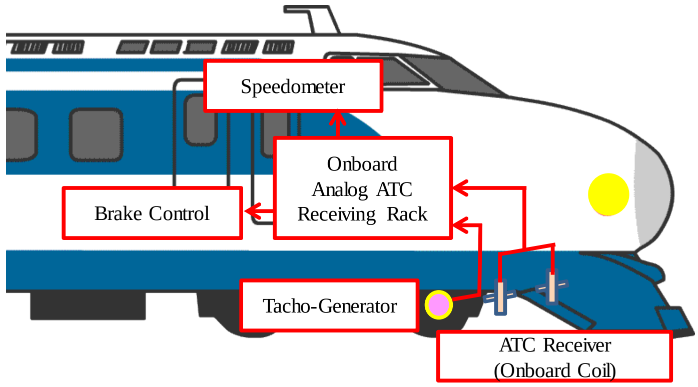
For increased speed/ high-density operations, the ATC of the Tokaido Shinkansen was also improved from a multi-stage brake control based on the original analog speed signal, to a one-stage brake control which automatically applies the brakes based on digital signals, so that the train can stop exactly at the required point. This brake control has the advantage of shortening braking distances and increasing ride comfort.

Regarding the basic configuration of the Analog ATC, the ground part and the onboard portion are shown in the below figures.



Source: JICA Study Team

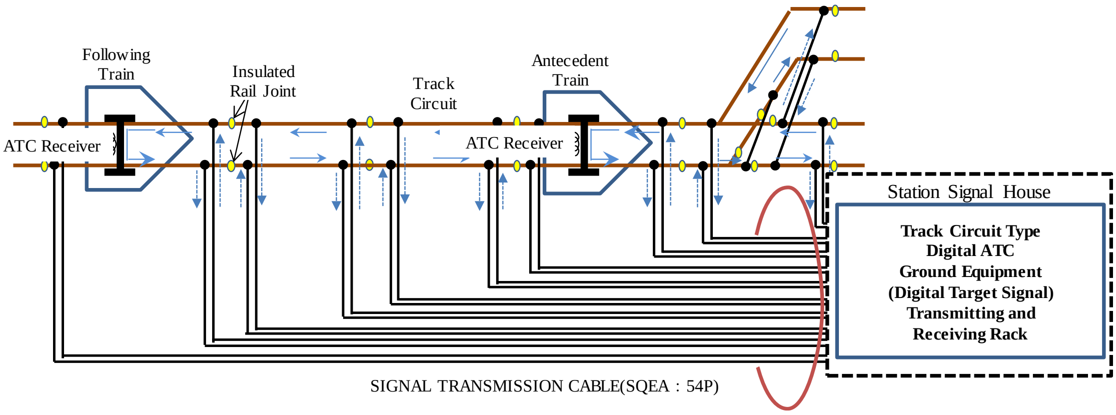
Figure 4.37: Configuration of the Ground System of Analog ATC



Source: JICA Study Team

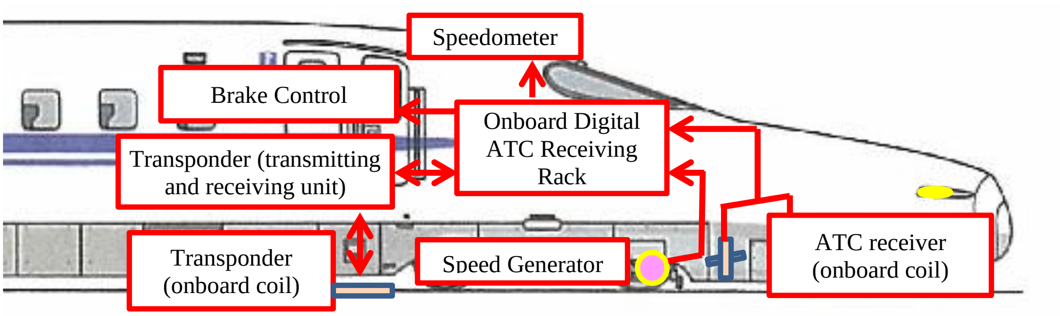
Figure 4.38: Configuration of the Onboard System of Analog ATC

For the basic configuration of the speed signal type ATC, the ground device and the onboard device are shown in the below figures.



Source: JICA Study Team

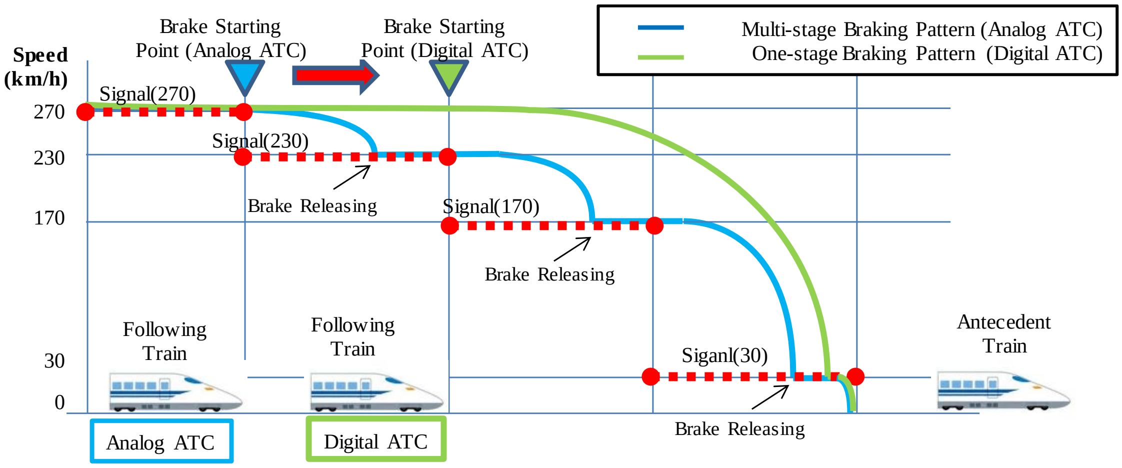
Figure 4.39: Configuration of the Ground System of Digital ATC



Source: JICA Study Team

Figure 4.40: Configuration of the Onboard System of Digital ATC

The next figure shows the comparison of typical ATC operation between analog and digital.



Source: JICA Study Team

Figure 4.41: Comparison of Analog ATC and Digital ATC

(2) Development of Digital Radio ATC for Shinkansen

1) Features of Digital ATC

The combination of the onboard autonomous speed control device and the one-stage brake control system realized the following improvements.

- **Feature 1:** Autonomous speed control

Speed control based on the train's operation is realized through the onboard computer which generates run curve based on the distance to the preceding train received from the ground device or the distance to the ATC course in stations (the number of track circuit sections), the railway track data, and the vehicle performance such as, maximum speed, acceleration/deceleration.

- **Feature 2:** Exercise of vehicle performance

Easiness of introducing new vehicles with higher performance, without any confinement from the performance envelope of old vehicles, when updating the vehicles.

- **Feature 3:** Improvement of ride comfort

Dramatically improved comfort that is realized by the braking force constantly acted from the maximum speed to stopping without repeating braking and remission.

2) Issues of Digital ATC

However, the digital ATC faces the following issues, especially for long lines such as Hanoi - HCMC.

- **Issue 1**: Fixed block section length

Since each track circuit detects the train position, the accuracy of the train position depends on a unit of one-track circuit length. Therefore, the following train must necessarily be stopped before the blocking section where the preceding train is located, and the train interval cannot be optimally controlled because of such track circuit length which is deemed as unnecessarily long from a train control point of view.

- **Issue 2**: Cost of track circuits

The length of one-track circuit is normally about 1 km, and the signal boxes are at the circuit boundary with the signal multicore cable from the station signal equipment room. Therefore, as the station intervals become long, the installation cost becomes expensive.

- **Issue 3**: Two-way operation on singletrack

Two-way operation on singletrack is useful for track maintenance. However, the construction cost is expensive to realize a two-way operation based on the track circuit system, because the modification of hardware is necessary for the track circuits.

3) RS-ATC (digital Radio communication and control for Shinkansen ATC)

i) Development History

In recent years, mobile communication technologies such as cellular phones have made remarkable progress, and this has prompted the movement to construct the next-generation train control system by applying this technology. Thus, a railway signal based on radio communication has become active internationally.

In November 2002, JR East (JRE) introduced a digital train radio to the Tohoku and Joetsu Shinkansen lines, enabling quality improvement of high-speed data transmission and high-speed, large-capacity transmission.

Utilizing the data system radio transmission of this digital train radio and using it for transmission of train control information between the ground and the vehicle, it is possible to realize the following functions.

- To adapt the two-way operation on a single track section.
- To realize the moving blocking operation.
- To slim down many existing signal facilities located between stations such as signal boxes and cables.

As such, JRE began studying RS-ATC (digital Radio communication for Shinkansen ATC) using LCX train radio to enable new functionality mentioned above.

However, at the present time, RS-ATC is in the stage of recertifying a similar system certified for conventional lines to Shinkansen.

Before the replacement of DS-ATC to RS-ATC, a considerable verification period is needed.

Therefore, since 2009, JRE had introduced the RS-ATC as a substitute security device sequentially to the Tohoku, Joetsu, Hokuriku Shinkansen, respectively.

At the same time, JRE had started verification work to confirm its safety and reliability.

ii) Status quo

As the first steps toward the realization of next-generation ATC equipment, RS-ATC is actively accumulating two-way data information transmission between the ground and the vehicle, even during ordinary operation by DS-ATC.

- To compare train positions detected by radio (RS-ATC) and by track circuit (DS-ATC), and to check the discrepancies between them.
- To confirm the radio transmission characteristics such as at the weak electric field part, the zone boundary, etc., and the operating ratio of the whole system.

Moreover, the radiotelegram in RS-ATC, transmitted from the onboard device to the ground device, includes the train ID information.

This train ID information can be used effectively by the station PRC (Programmed Route Control) system[17].

Therefore, at the time of RS-ATC implementation, the conventional train ID transceiver devices installed at each station are removed.

4) VHSR-ATC (Vietnam HSR-ATC)

i) Configuration and functions

VHSR-ATC (Vietnam HSR-ATC) is recommended as a signaling system for Vietnam High Speed New Line (350 km/h) because the distance between the stations is long, and two-way operation is required from the viewpoint of track maintenance. VHSR-ATC can simplify the signal facilities in the middle of the station and enables two-way operation. The concept of VHSR-ATC is as follows.

- The function of the ground device
  - To determine the target distance from the received "train position" by track circuit to "stop/deceleration target point."
  - To transmit "distance to stop / deceleration target point" to the onboard device in real-time (about 1-second intervals).
  - To receive train ID with position from the onboard device in real-time (about 1-second intervals).

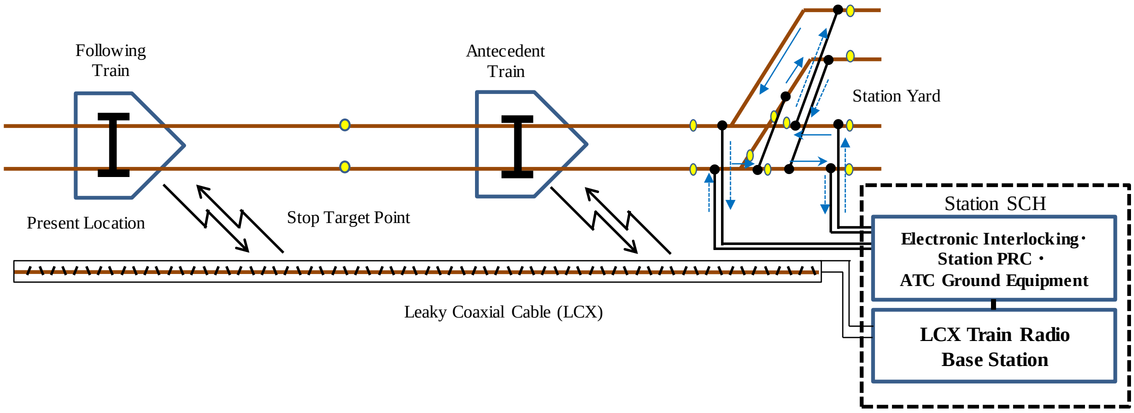
- The function of the onboard device
  - To transmit train ID with position to the ground device in real-time (about 1-second intervals).
  - To receive "distance to stop / deceleration target point" in real-time (about 1-second intervals) from the ground device.

[17] PRC is a kind of Automated Route Control system which makes the interlocking device to switch turnouts, display signal aspects, and interlock the route based on the train operation plan. It monitors the arrival and departure of trains, and broadcasts the automatic public announcement for passengers as well.

- To create a "brake curve profile" that matches the received "distance to the stop/deceleration target point," the current position and speed of the train, and line information of the onboard database, and perform necessary one-stage brake control.

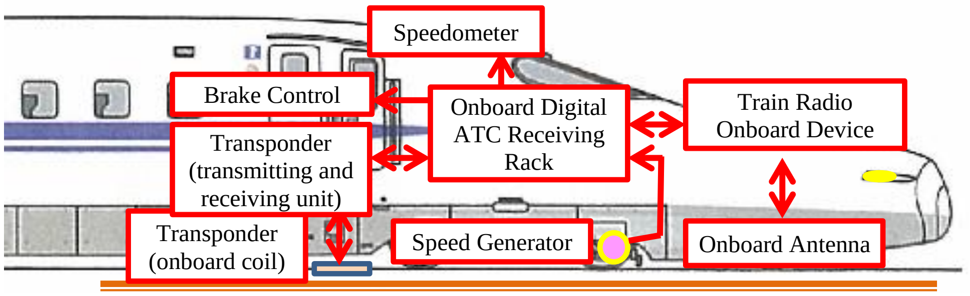
Accordingly, the following train can approach up to just before the track circuit where the other train is currently located.

Regarding the basic configuration of VHSR-ATC, the ground device and the onboard device are shown in the below figures.



Source: JICA Study Team

Figure 4.42: Configuration of the Ground System of VHSR-ATC



Source: JICA Study Team

Figure 4.43: Configuration of the Onboard System of VHSR-ATC

ii) Development Concept

- Improvement of safety and efficiency of train control

By enabling VHSR-ATC to transmit the information on “Distance to stopping/speed target point” and “Train direction between stations” from the ground device to the onboard device at one-second intervals wirelessly, the following improvements on functions are realized.

- To set (or reset) two-way operation on a double track section arbitrarily from the Operation Control Center.
- To control the train speed efficiently by one-stage brake control

As a result, VHSR-ATC improves the safety and efficiency of train control, as compared with the conventional track circuit type DS-ATC.

- Significant simplification of the signaling equipment between stations

  For train detection between stations, long track circuit sections of 5 km intervals can be used.
  As the number of track circuits are reduced by 1/5 of DS-ATC, the installation cost of signal equipment can be reduced.
  However, the train position in the station yard shall be detected precisely using the insulated track circuit of train speed.
  The below table shows the main differences between DS-ATC, RS-ATC, and VHSR-ATC.

Table 4.51: Main Differences among DS-ATC, RS-ATC, and VHSR-ATC

Item			DS-ATC	RS-ATC	VHSR-ATC
①	Operation Direction	Normal	○	○	○
		Reverse	×	○	○
②	Number of Train		Multiple	Single	Multiple
③	Block System		Fixed Block	(substitute safety system)	Fixed Block
④	Maximun Speed		≧200km/h	110 km/h	≧200km/h
⑤	Detection Method	Train Location	Track Circuit	Axle Counter	Track Circuit
		Train ID	Radio(RS-ATC)	Radio	Radio
⑥	Stop Target Point		Boundary of Track Circuit	×	Boundary of Track Circuit
⑦	ATC Control Transmission	ground →onboard	Track Circuit	×	Radio
		onboard→ground	×	×	Radio(Train ID)
⑧	Vehicle Condition Transmission		×	×	Radio

Source: JICA Survey Team

- The ground system
  - Detection of train position
    The ground device detects the train position using insulated track circuits within the station yard and using long track circuits between stations.

  - Securing the driving direction
    The direction levers for the interlocking panel are provided at each station, and the driving directions of "forward line" and "reverse line" are secured for both lines.

  - Creation of “stop/speed limit telegrams”
    "Stop/speed limit telegrams" for each train is created from the position of each detected train, establishing temporary speed restricted areas for work, natural disasters, etc.

  - Transmission of "stop/speed limit telegrams"
    The ground device writes the "stop/speed limit telegram" in the radio time slot of the corresponding train and transmits it to the onboard device.

- Information Input to the station PRC
  The ground device inputs the train ID and position in the "train location telegram" to the station PRC device, and causes the ATC route control to be executed.

- The Onboard system

  - Creation of speed verification pattern
    The onboard device generates speed check patterns for "stop/speed limit message" received from the ground each time it is received.
    There are two types of speed check patterns: NB (service brake) and EB (emergency brake).
    In VHSR-ATC, the maximum speed of the line will be applied on both the forward and reverse lines.

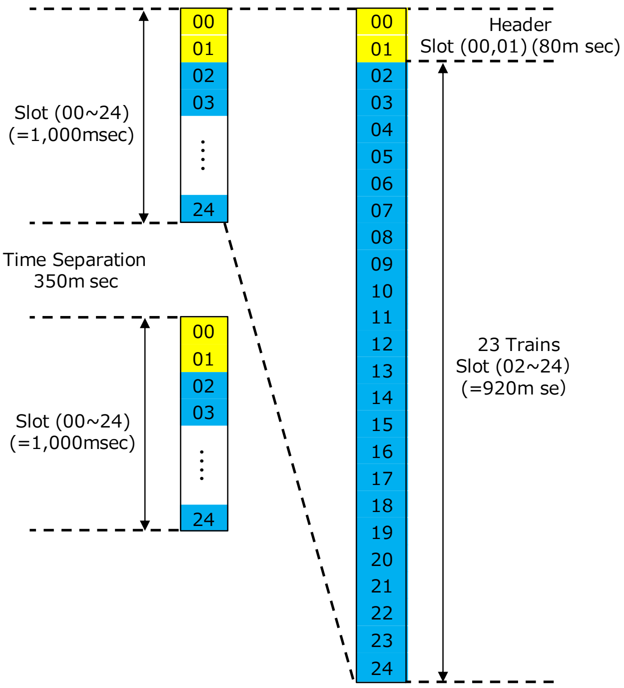
  - Speed check and brake control
    The onboard device crosschecks the speed indicated by the generated speed check patterns with the current train speed and automatically controls the brakes as necessary.
    The driver shall handle brake operation at the time of stoppage as currently.

  - Monitor screen of the cab
    Like DS-ATC, the onboard device displays the current position, current speed, speed check pattern, and so forth on the monitoring cab screen.

iii) LCX radio data transmission

- Securing a dedicated channel
  - The radio equipment used for VHSR-ATC shall be LCX digital train radio.
  - 4 channels out of 15 for data communication (9.6 kbps per channel) are secured exclusively for VHSR-ATC.
  - Out of these channels, VHSR-ATC assigns channels 1&3-for the uplink train/ 2&4-for down train and configures up and down the double system.

- Time slot allocation method
  - If one channel were to be occupied by one train, the number of trains that can be controlled would be insufficient. Therefore, each channel is time-divided into 25 slots/second, where one slot is allocated to one train.
  - The message transmission is set to a period of 1,350 ms, and the idle time for not transmitting the telegram is secured at 350 ms.
  - Two of the 25 slots are used for initial setting, and train control is possible simultaneously for 23 trains in one zone of each radio base station.
  - The assignment of slots to each train and the reservation of new slots when crossing the control station (zone) boundary are executed by the ground radio device.
  - An example of VHSR-ATC time-division slot allocation is shown in the below figure.



Source: JICA Study Team

Figure 4.44: An Example of VHSR-ATC Time Division Slot Allocation

- The procedure of ATC transmission
  - Unlike ATC control telegrams in DS-ATC, ATC control telegrams in VHSR-ATC are received at the same time by all trains within one radio zone.
  - Therefore, it is necessary that the onboard device is synced on whether it is addressed to the relevant train.
  - As a key for judging whether it is directed to the own train or not, the mobile station number (1 to 255) of the on-train device uniquely assigned to each onboard device is added.
  - The main specifications of VHSR-ATC are shown in the below figure.

Item		Element
Modulation Scheme		π/4 shift QPSK 2-wave digital train data system
Train Control Channel		Data System 4 channels (downlink, uplink each 2CH)
Error Correction Code Level		Bit Error Rate ≤ 10^-4
Transmission Speed	ATC Ground Device (logic section) → Base Station	64 kbps
	Base Station → Mobile Station	9.6 kbps
Frame Length	40 msec /train	384 bit (=48 × 8 bit)
Transmission Cycle	ATC Control Message: (A→B)	1,350 msec
	Train Location Message: (B→A)	1,350 msec
Maximum Number of Controlled Trains		down, up each 23 Trains / 1 Control Station (zone)

(Reference) DS-ATC Track Circuit Transmission System

- Carrier Frequency in Track Circuit (Down Line 1.5 kHz, Up Line 1.6 kHz)
- ATC Control Message: (A→B)
- Transmission Speed: 64 bit/sec
- Data Verification Method: Cyclic Redundancy Check CRC

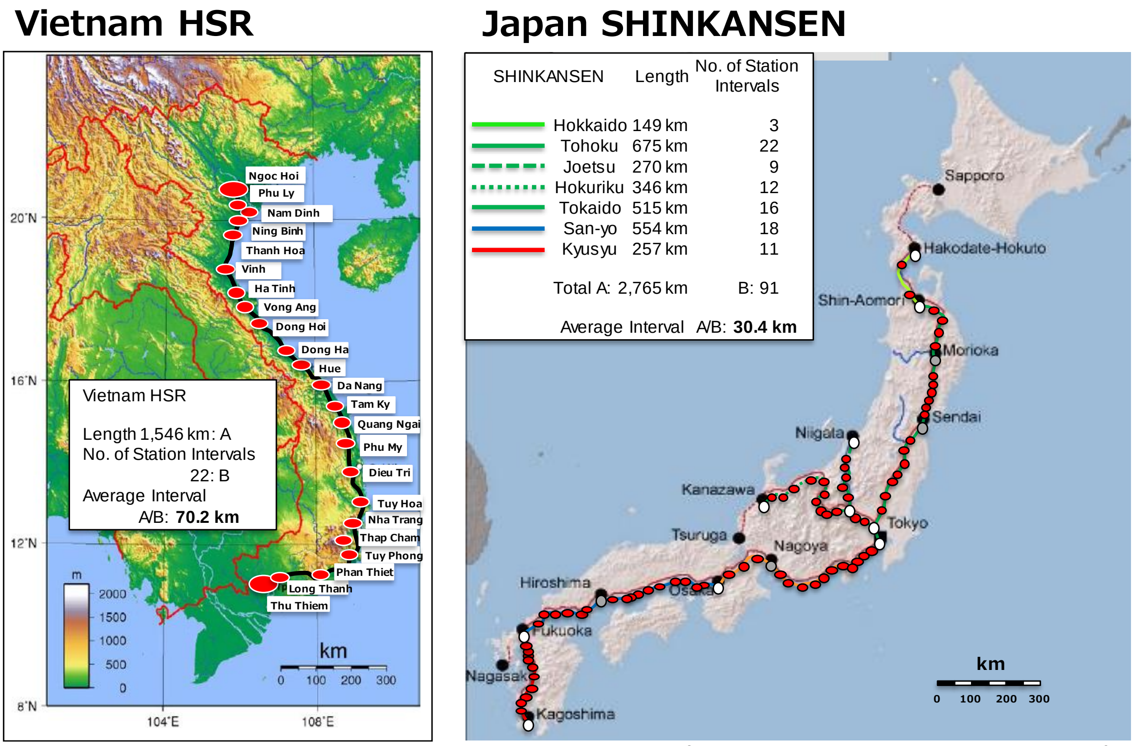
Frame Length 75 bit; Message 58 bit

Header	Track Circuit ID (15 bit)			Route Code	Open Section Number	Information Number	Speed Limit	Speed Limit TC Start ID	Speed Limit TC Start No.	CRC Code
	Line Code	Section Code	TC Code							
7 bit	3 bit	5 bit	7 bit	5 bit	5 bit	5 bit	8 bit	15 bit	5 bit	10 bit

Source: JICA Study Team

Figure 4.45: Main Specification of VHSR-ATC

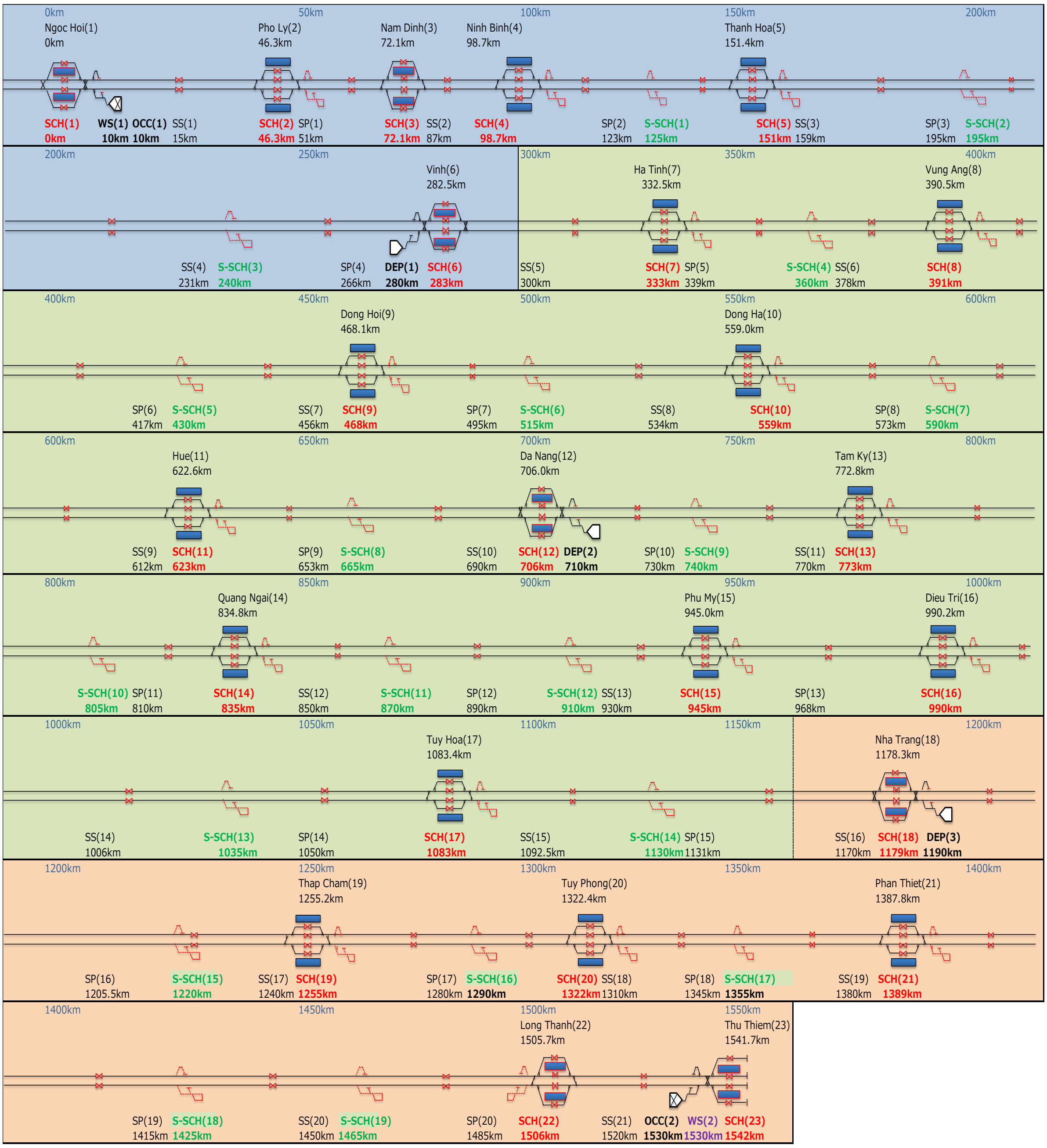
Reference Material 1: The Average Interval Distance between Stations



Source: JICA Study Team fill in table and stations on topographic map[18] (Sadalmelik, 2007) and Shinkansen map[19] (UIC, 2015)

[18] https://upload.wikimedia.org/wikipedia/commons/7/75/Vietnam_Topography.png (Referenced 2019.07.12)
[19] https://uic.org/high-speed-database-maps (Referenced 2019.07.12)

Reference Material 2: Outline of VHSR Facilities (Signal/Communication)



LEGEND OCC: Operational Control Center, SCH: Signal/Communication House, S-SCH: Sub SCH, WS: Work Shop, SS: Sub Station, SP: Sectionaring Post, SSP: Sub SP, DEP: Destribution Electric Post
North Area Middle Area South Area

Source: JICA Study Team

4.4 Rolling Stock and Depot

4.4.1 Rolling Stock

(1) Basic Concept

1) High-Speed and Safety

The social effect of a high-speed train is significant. It not only shortens travel times but also can stimulate new demand. Economic development along the line is highly expected. 50 years of Shinkansen history in Japan shows this as a fact. On the other hand, safety is highly necessary for high-speed train operation. The risk of a high-speed train is much higher than that of a conventional train because failure to notice even the most trivial incident may lead to a fatal accident. Safety of high-speed trains cannot be maintained by human attention alone. Therefore, an advanced safety system is required. The Japanese Shinkansen has not had a single fatal accident in its 50+ year history.

2) Core Features

Dedicated standard gauge tracks should be introduced to maintain safe operation of the high-speed train. Therefore, using conventional lines should not be considered. For stabilized high-speed train operation of more than 300 km/h, a distributed traction system such as EMU should be adopted. The advantage of EMU is not only high power and low coefficient of adhesion in power, but also, the regenerative brakes can share brake force without pneumatic friction brakes.

For compatibility of heavy transportation with low initial cost track, wide car body (5 seats per row) can be operated at a speed of more than 300 km/h on a narrow trackbed (4.3 m distance between track centers) and small cross-section tunnels (64 m²). These core features are proven in the design of the Japanese Shinkansen.

3) Further Consideration

For environmental condition, reduction of noise and vibration caused by high-speed operation is considered. For energy savings; light car body, light bogie, and the effective regenerative brakes have been innovated. These are utilized in the series E5 of the Tohoku Shinkansen.

Source: Outline of JR East E5 Shinkansen train (mass production leading vehicle) (Vehicle Technology No. 239, 2010-3)

Figure 4.46: Series E5 of Tohoku Shinkansen

(2) Basic Specification

The following table shows the basic specifications of rolling stock for VHSR. It is based on the series E5 of Tohoku Shinkansen.

Table 4.52: Basic Specifications of Rolling Stock for VHSR

Item	Specification
Track gauge	1,435 mm
Power supply	AC25 kV 50 Hz
Maximum speed	350 km/h (design), 320 km/h (operation)
Train configuration[20]	10 cars (8M2T), 16 cars (14M2T) in future
Seat type	Reclining & turning type
Passenger capacity	10 cars: 740 (Executive C. 55, Economy C. 685) 16 cars: 1,220 (Executive C. 122, Economy C. 1,098)
Total weight (unloaded)	10 cars: Approx. 460 t, 16 cars: Approx. 740 t
Maximum axle load	14 t (100% passenger load)
Major dimensions	
Length (lead car)	26,250 mm
Length (middle car)	25,000 mm
Maximum width	3,350 mm
Maximum height	3,650 mm
Distance between bogies	17,500 mm
Body structure type	Aluminum alloy double-skin extruded structure (Airtight structure body)
Bogie	
Type	Bolster-less type
Wheel diameter	860 mm (new wheel)
Wheelbase	2,500 mm
Propulsion system	
Control system	Converter-Inverter VVVF control system (IGBT 3 level PWM)
Traction motor	Induction motor 300 kW
Pantograph	Single-arm & low noise type 10 cars: use 1 of 2 units, 16 cars: use 2 of 4 units
Brake system	Electric command system with regenerative brakes
Safety system	Digital ATC with onboard brake control
Train radio	Space wave & LCX (digital)

Source: JICA Study Team

(3) Particular Technologies

The following particular technologies of series E5 which have been developed in the Japanese Shinkansen shall be adopted to VHSR. These proven designs contribute to safety, reliability, availability, maintainability, and cost reduction.

1) Wide Car Body

Wide car body enables 5-seat rows in economy class. Enlargement of the capacity of each car contributes to the reduction of the number of cars and cost of rolling stock.

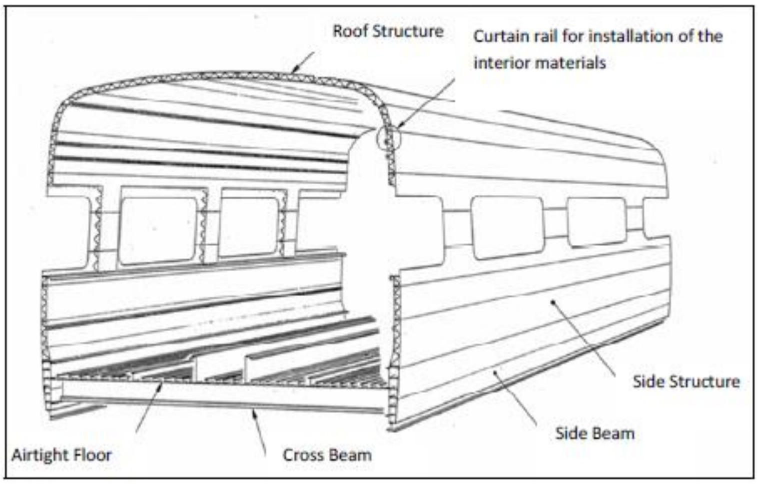
[20] 5 cars, 3M2T (Five-step-development Case, between Long Thanh and Thu Thiem, 2030 - 2040)

Source: Outline of JR East E5 Shinkansen train (mass production leading vehicle) (Vehicle Technology No. 239, 2010-3)

Figure 4.47: Economy Class of E5 **Figure 4.48: Executive Class of E5**

2) Lightweight Car Body

The car body weight and axle load are reduced with an aluminum double skin structure while maintaining body strength. Being lightweight contributes to reducing the energy consumption and operating cost. Light axle loads have a big impact on reducing construction costs.



Source: Previous Study (JICA, 2013)

Figure 4.49: Aluminum Double Skin Extruded Structure

3) Propulsion System

Induction motors and the VVVF control system contribute to reducing the maintenance work for the propulsion system. Effective regenerative brakes of this system contribute to reducing energy consumption and maintenance work on the brake pads.

4) Digital ATC

Digital ATC system supports safe operations. The cab signal will be indicated with train speed on the monitor screen in front of the driver. It creates the brake commands based on its calculated running pattern. Lightweight car body based on crash avoidance can be realized by the reliability of digital ATC. The VHSR-ATC proposed in this study is improved, enabling two-way operation at high speed.

5) Long Nose Shape of Lead Car

Micro pressure waves at the tunnel is one of the most serious problems of the high-speed railway. If tunnel cross-section is bigger, this problem will be alleviated, but the construction cost will be increased. For the reduction of micro pressure wave effect without enlarging the tunnel cross section, a long nose shape (15 m) of lead car shall be incorporated.

6) Noise Reduction of Pantograph

The pantograph is one of the main noise sources. Low noise pantographs are equipped with deflectors that stabilize airflow. There are two pantographs per 10 cars, but only one pantograph at the rear side of the train is used while running to reduce noise.

Source: Outline of JR East E5 Shinkansen train (mass production leading vehicle) (Vehicle Technology No. 239, 2010-3)

Figure 4.50: Pantograph and Deflector of Series E5

7) Full Active Suspension

The full active suspension system is equipped on all cars. The control unit of this system detects the lateral vibrations from the sensor unit and controls the actuator activity to reduce vibrations.

(4) Maintenance Interval

Maintenance intervals based on Japanese Shinkansen are shown in the below table.

Table 4.53: Maintenance Intervals of Rolling Stock

Type	Inspection points	Interval	Venue	Duration
Daily Inspection	Operation and function of pantographs, running gears, brakes, door operating system, etc.	Less than 48 hours	Depot or Workshop	Approx. 1 hour
Regular Inspection	Conditions and function of pantographs, main circuit system, control system, brake system, bogies, and insulation of electric parts,	Less than 30 days or 30,000 km	Depot or Workshop	1 day

Type	Inspection points	Interval	Venue	Duration
Bogie Inspection	Main parts of body, e.g., wheelsets, driving device, brake device, traction motors, etc., shall be disassembled from bogies. The efficiency of the inspection shall be guaranteed with the use of a bogie replacement system, i.e., temporary replacement of the bogies to be inspected with a backup bogie.	Less than 18 months or 600,000 km	Workshop	Approx. 3 days, temporary replacement of bogies
General Inspection	The detailed inspection shall be carried out for main equipment disassembled from cars. The efficiency of the inspection shall be improved by replacing the equipment to be inspected with a back-up. At the same time, bodies shall be repainted, and passenger cabin equipment shall be repaired.	Less than 36 months or 1,200,000 km	Workshop	Approx. Three weeks

Source: JICA Study Team

(5) Future Prospects

1) Maximum Speed Restriction at beginning

There is a plan to restrict the maximum speed (<250 km/h) at the beginning of service and increase maximum speed (>300 km/h) later when the entire line is opened. This speed restriction is not recommended, because the difference of the initial cost of rolling stock for either speeds is not much, and additional track work (increase of cant on curves) will be needed when the entire line is opened.

2) Night Train Service between Hanoi and Ho Chi Minh

After the entire line is opened, the travel time will be approx. 6 hours. The night train service using sleeping cars will be useful in this case. For example, night train departs from Hanoi after the departure of the last flight and arrives at Ho Chi Minh the next morning before the arrival of the first flight from Hanoi.

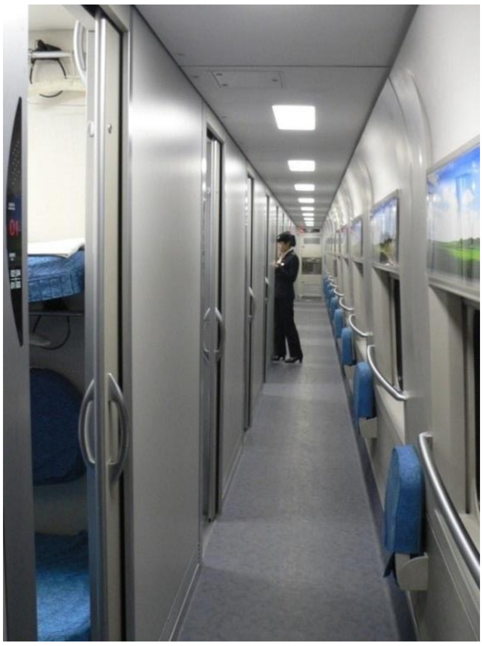
One critical item is to keep maintenance time for track or catenary work at midnight. There are two solutions, and (ii) is recommended.

(i) One track is in maintenance; night train runs on other track at low speed.
(ii) Night train dwells at a station during maintenance time (0:00 – 6:00).

Unfortunately, Japanese Shinkansen has no night train because of the short travel time. The following photos are an example in China (CRH2E); the dimension of the car body is almost the same as series E5.

Source: JICA Study Team

Figure 4.51: Compartment of CRH2E



Source: JICA Study Team

Figure 4.52: Aisle of CRH2E

4.4.2 Depot

(1) Depot Installation

In this study, five depots have been determined for storage and maintenance of vehicles (Wheel turning, Vehicle Washing, Trip inspection, Regular inspection, General inspection). Five depots are set considering the phasing and the distance between depots. The overview of each depot is shown in the below table. Furthermore, workshops are set to be in each of the two sections operated in the earlier phase.

The number of storage lines for each depot is set from the operation plan of 2030, 2040, 2050, and 2070. The number of inspection lines and the space required for various buildings is set by referring to cases of the Japanese Shinkansen.

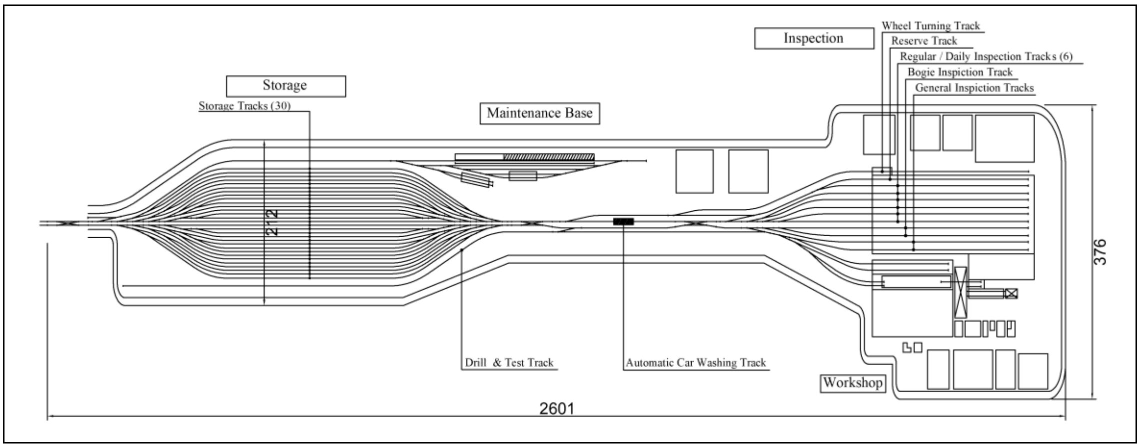
Table 4.54: Overview of each Depot

	Storage		Inspection Lines						Workshop	Area
	Rolling stocks	Lines	Daily	Regular	Turning	Reserve	Bogie	General		(ha)
Ngoc Hoi	25	28	3	3	1	1	2	2	Included	54.7
Vinh	10	11	2	1	1	1	-	-	-	25.4
Da Nang	30	33	4	3	1	1	-	-	-	48.1
Nha Trang	16	18	2	2	1	1	-	-	-	30.7
Thu Thiem	27	30	4	3	1	1	2	2	Included	57.1

Source: JICA Study Team

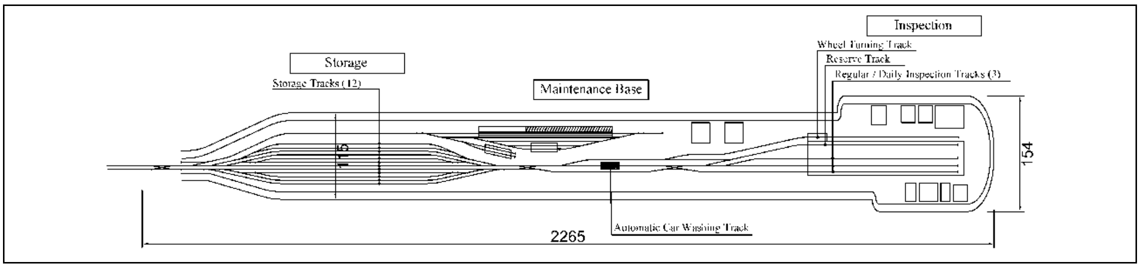
(2) Track Layout

The track layout of each depot is shown in Figure 4.53 to Figure 4.57. Each depot has a maintenance base.



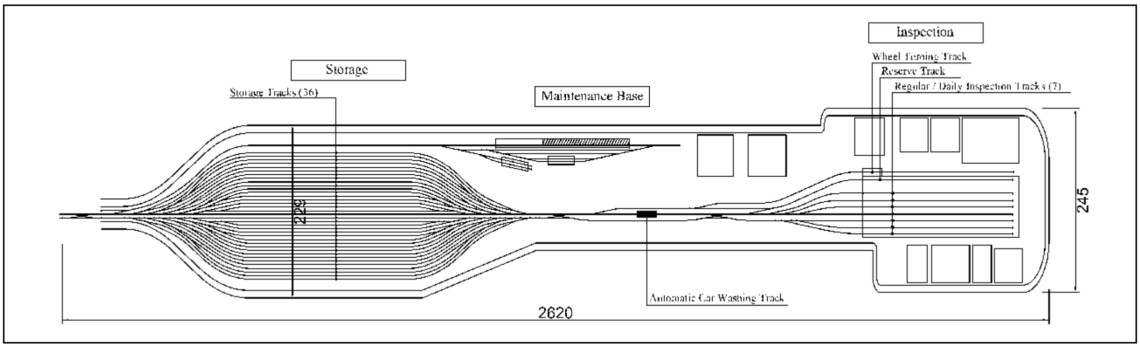
Source: JICA Study Team

Figure 4.53: Ngoc Hoi Depot Track Layout



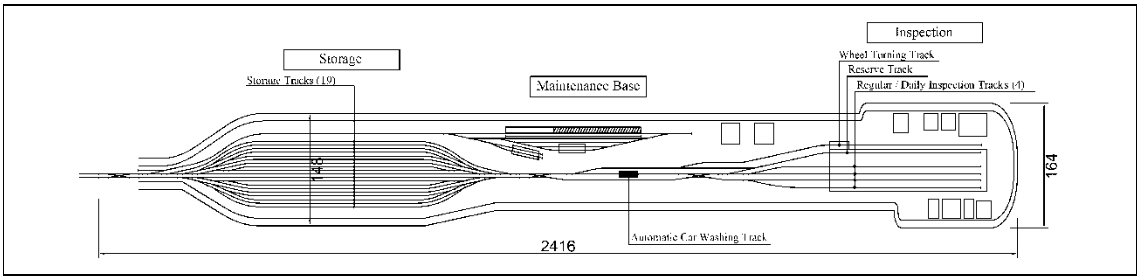
Source: JICA Study Team

Figure 4.54: Vinh Depot Track Layout



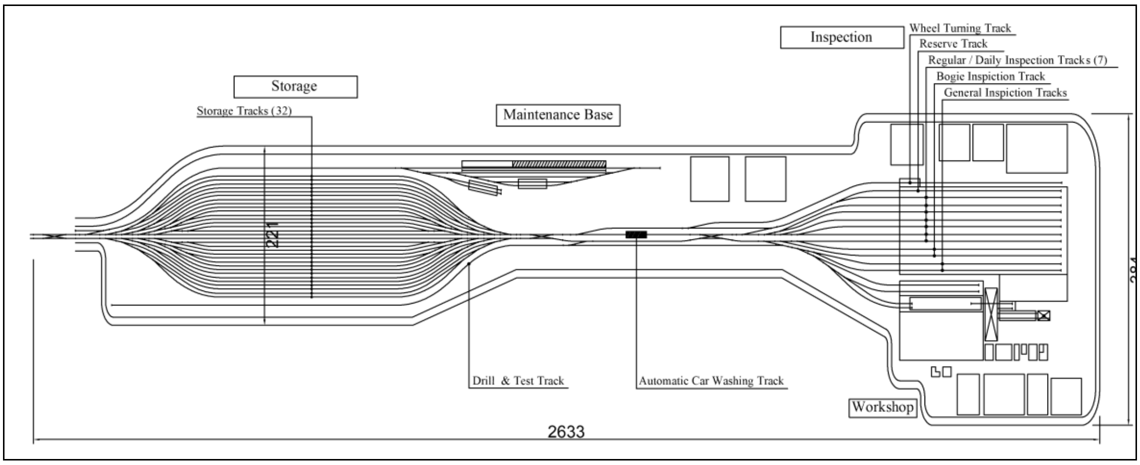
Source: JICA Study Team

Figure 4.55: Da Nang Depot Track Layout



Source: JICA Study Team

Figure 4.56: Nha Trang Depot Track Layout



Source: JICA Study Team

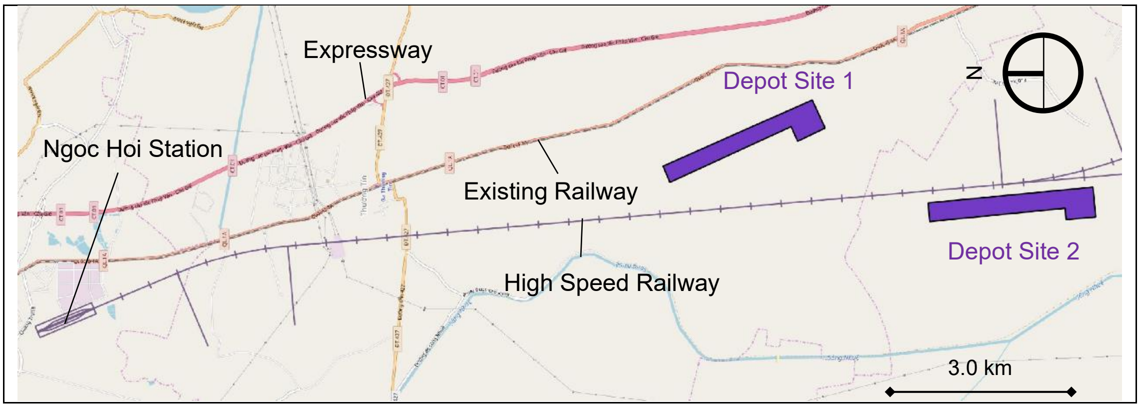
Figure 4.57: Thu Thiem Depot Track Layout

(3) Depot Location

Here, potential locations for each depot are listed. The candidate sites listed are examples only, and it is the first priority to secure the base of the depot according to local circumstances through local consultations.

1) Ngoc Hoi Depot

Here, as candidate land of the depot, two sites are cited approximately 10 km south from Ngoc Hoi station. Since the station's northern side has already been developed, it is very difficult to secure enough land for the depot. Also, the area from the station to approximately 10 km is difficult to secure land for depot because of villages scattered throughout.



Source: JICA Study Team

Figure 4.58: Ngoc Hoi Depot Location

2) Vinh Depot

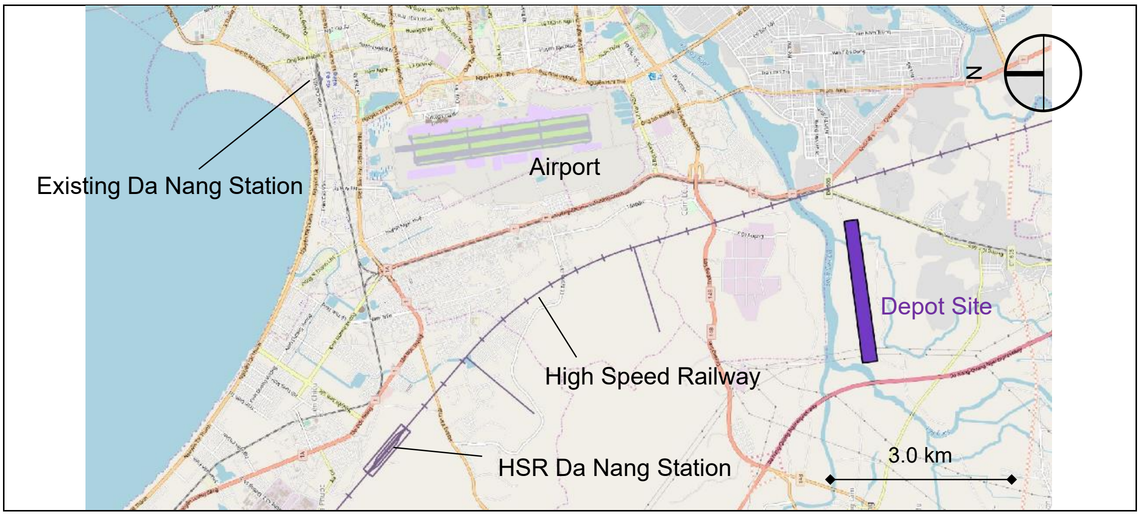
Here, as a candidate spot for the depot, two sites are cited one by one at the starting side and the ending side of the station. The possibility for both sites is high because both sites are relatively close to the station.

Source: JICA Study Team

Figure 4.59: Vinh Depot Location

3) Da Nang Depot

In the northern area, it is difficult to secure land for a depot site because the area to the north of the station is quite developed. Also, the northern area consists of hilly land. In the southern area, there are relatively wide flatlands south of the river, approximately 8 km from the station. Thus, here, one site is planned for the depot.

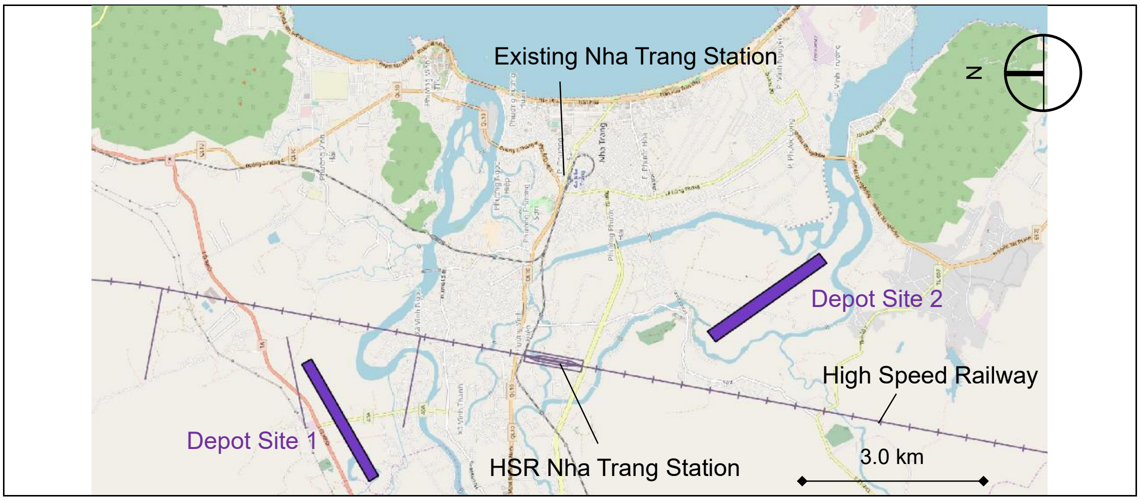


Source: JICA Study Team

Figure 4.60: Da Nang Depot Location

4) Nha Trang Depot

In the northern area, the depot candidate site is set in farmland on the north side of the river. It is difficult to secure a wide area on the south side of the river because residential areas are densely located. In the southern area, the farmland south of the river is a candidate site. The site in the south is close to the station, and an approach route is also favorable, but the northern site seems to have better geology.

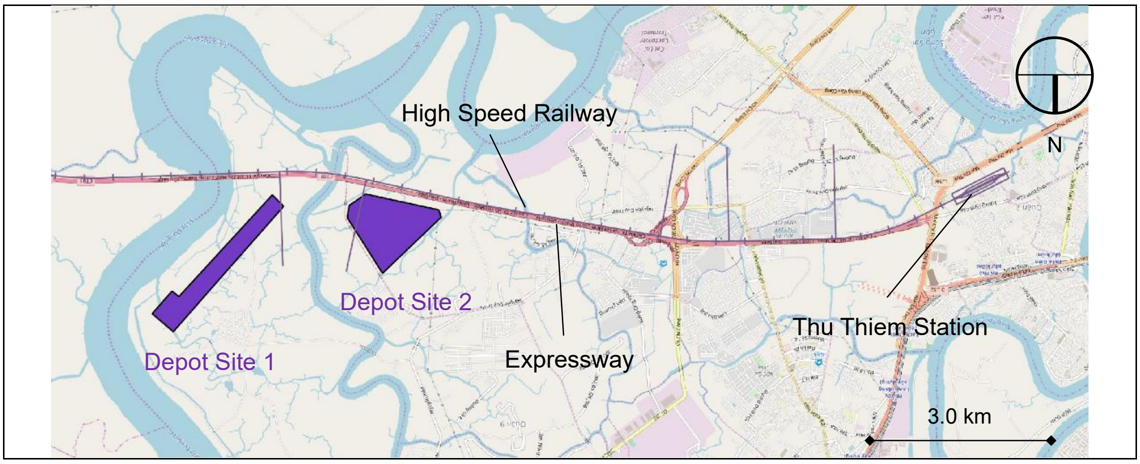


Source: JICA Study Team

Figure 4.61: Nha Trang Depot Location

5) Thu Thiem Depot

There is no appropriate wide site for the depot in the area from the station within 10 km. Two sites are set as a candidate in the area with only a few buildings. In both cases, the approach from the main line to the depot needs to go beyond the expressway. Site 2 is not long enough to accommodate a linear type depot, meaning it would need to be a parallel type. Site 1 can secure a sufficient straight-line length, but some residential relocation is required. If these candidates cannot be used, the depot shall be installed at the east side of the river.



Source: JICA Study Team

Figure 4.62: Thu Thiem Depot Location

(4) Maintenance Base

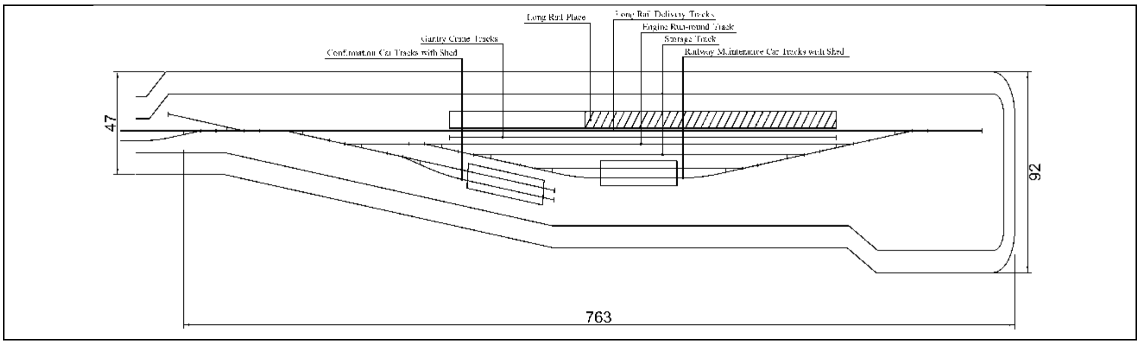
1) Maintenance Base Installation

In order to maintain the track, maintenance bases are set at approximately 50 km intervals. The total number of maintenance bases is 42. Five of them are in the depot. Therefore, the number of standalone maintenance bases are 37.

Maintenance is conducted in a limited amount of time outside of operating hours. When the maintenance depot interval becomes longer, more time is required for a round trip, and work efficiency would decrease. For this reason, in Japan, the standard for maintenance depot intervals is from 30 to 50 km. The location of the maintenance depots is shown in Figure 3.7: Track Layout.

2) Maintenance Base Track Layout

A single maintenance base track layout is shown in Figure 4.63. The open space in the figure is the space for buildings and warehouses.



Source: JICA Study Team

Figure 4.63: Maintenance Base Track Layout

4.5 Estimated Construction Costs

This section has been removed because of confidential information.

5. Railway Operation

5.1 Train Operation Plan

5.1.1 Outline

HSR's operation plans are prepared considering both Two-step Case and Five-step Case, as described in Chapter 2.1. In Two-step Case, the entire section is divided into three construction sections. The northern and southern sections are assumed to start operations in 2030, and the middle section in 2040. On the other hand, Five-step Case calls for the entire route to be divided into five construction sections. The Long Thanh – Thu Thiem section is assumed to start operation as a single-track line by 2030, the Hanoi – Vinh section as a double-track line by 2040, Nha Trang – Thu Thiem section as a double-track line by 2050, Da Nang – Nha Trang section as a double-track line by 2060, and Vinh – Da Nang section as a double-track line by 2070.

5.1.2 Outline of Train Operation Plan (Two-step Case)

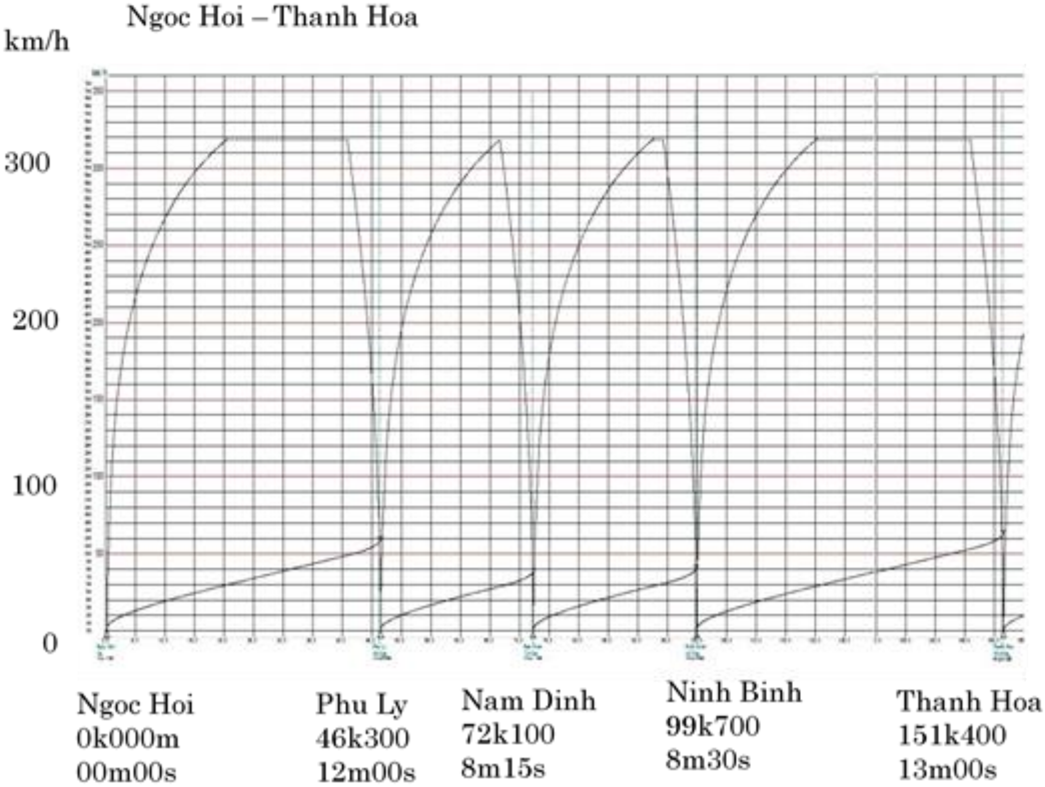
(1) Preconditions for Train Operation Planning

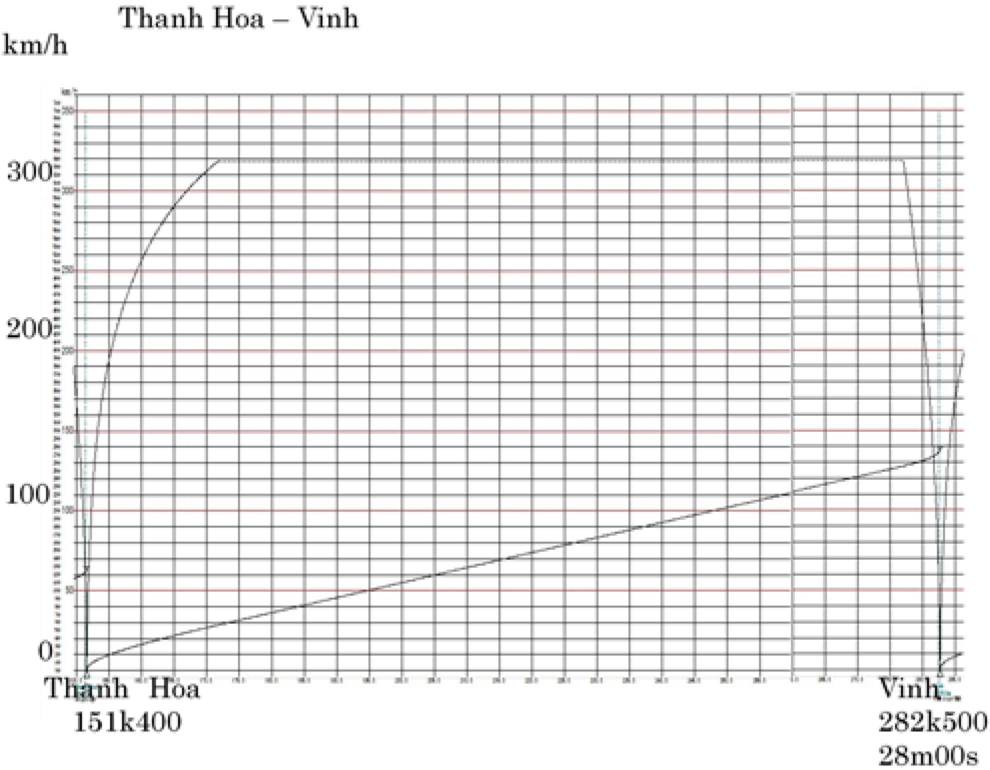
HSR's operation plan is formulated on the following assumptions:

1) Operation starts between Ngoc Hoi – Vinh and Nha Trang – Thu Thiem by 2030
2) Operation of the entire line between Ngoc Hoi – Thu Thiem starts by 2040
3) Demand is the forecasted amount in this survey for years 2030, 2040, 2050
4) The maximum speed is 320 km/h; the capacity is 740 people for 10 train sets, 1,220 people for 16 train sets
5) The operating hours have been set to 6:00-24:00

(2) Operating Time Between Stations

Under the above preconditions, the run curve between each station is created (Figure 5.1 shows an example between Ngoc Hoi – Vinh). Based on the run curve, the operating time between stations are calculated, as shown in Table 5.1 and Table 5.2. The time required between Ngoc Hoi – Thu Thiem is 7 hours and 15 minutes for the local train, and 5 hours and 20 minutes for the express train (including the stoppage time and margin time for various adjustments.)





Source: JICA Study Team

Figure 5.1: An Example of a Run Curve (Ngoc Hoi – Vinh)

(3) Required Number of Trains

The number of trains one way for one day is 36 between Ngoc Hoi – Vinh in 2030, and 36 between Nha Trang – Thu Thiem as well. The operation between Ngoc Hoi – Thu Thiem will start in 2040 and 2050, and the number of trains will be increased to 72 ~ 90.

The passenger volume between stations and the number of trains are shown in Table 5.3 and Table 5.4.

5.1.3 Operation Plan

Local trains (stops at all stations) and express trains (stops only at specific stations to shorten the overall time to traverse route) are set as the types of train services. Vinh, Da Nang, Nha Trang, Long Thanh are set as stations where express trains stop, in consideration of the number of passengers getting on and off trains, availability of depots, schedule of international airport, etc. For 2030, since the number of trains is small, only local trains are assumed.

Stoppage time at stations are set as 2 minutes for each station. In the actual train schedule, the time required for each train will be changed according to the type of station, bypassing trains, etc.

Table 5.1: Operating Time (Ngoc Hoi → Thu Thiem)

	Station name	Center of station (m)	Between station (m)	Operating time		Standing time
				Local train	Express train	
1	Ngoc Hoi	0				
			46,300	12 : 00		
2	Phu Ly	46,300				2:00
			25,800	8 : 15		
3	Nam Dinh	72,100				2:00
			27,600	8 : 30		
4	Ninh Binh	99,700				2:00
			51,700	13 : 00		
5	Thanh Hoa	151,400				2:00
			131,100	28 : 00		
6	Vinh	282,500			0:57:00	2:00
			50,000	12 : 45		
7	Ha Tinh	332,500				2:00
			58,000	14 : 15		
8	Vung Ang	390,500				2:00
			77,600	18 : 00		
9	Dong Hoi	468,100	0			2:00
			90,900	20 : 30		
10	Dong Ha	559,000	0			2:00
			63,600	15 : 15		
11	Hue	622,600	0			2:00
			83,400	19 : 00		
12	Da Nang	706,000	0		1:23:45	2:00
			66,800	16 : 00		
13	Tam Ky	772,800	0			2:00
			62,000	15 : 00		
14	Quang Ngai	834,800	0			2:00
			110,200	24 : 00		
15	Phu My	945,000	0			2:00
			45,200	11 : 45		
16	Dieu Tri	990,200	0			2:00
			93,200	20 : 45		
17	Tuy Hoa	1,083,400	0			2:00
			94,900	21 : 15		
18	Nha Trang	1,178,300	0		1:32:45	2:00
			76,900	17 : 45		
19	Thap Cham	1,255,200	0			2:00
			67,200	16 : 00		
20	Tuy Phong	1,322,400	0			2:00
			65,400	15 : 45		
21	Phan Thiet	1,387,800	0			2:00
			117,900	25 : 30		
22	Long Thanh	1,505,700	0		1:05:30	2:00
			36,000	10 : 00		
23	Thu Thiem	1,541,700			0:10:00	
				6:03:15	5:09:00	0:42:00

Operating Time	6:03:15	5:09:00
Standing Time	0:42:00	0:08:00
Extra Time	0:29:45	0:03:00
Total	7:15:00	5:20:00

Source: JICA Study Team

Table 5.2: Operating Time (Thu Thiem → Ngoc Hoi)

	Station name	Center of station (m)	Between station (m)	Operating time		Standing time
				Local train	Express train	
1	Thu Thiem	0				
			36,000	10 : 00		
2	Long Thanh	36,000			0:10:00	2:00
			117,900	25 : 30		
3	Phan Thiet	153,900	0			2:00
			65,400	15 : 45		
4	Tuy Phong	219,300	0			2:00
			67,200	16 : 00		
5	Thap Cham	286,500	0			2:00
			76,900	17 : 45		
6	Nha Trang	363,400	0		1:05:30	2:00
			94,900	21 : 15		
7	Tuy Hoa	458,300	0			2:00
			93,200	20 : 45		
8	Dieu Tri	551,500	0			2:00
			45,200	11 : 45		
9	Phu My	596,700	0			2:00
			110,200	24 : 00		
10	Quang Ngai	706,900	0			2:00
			62,000	15 : 00		
11	Tam Ky	768,900	0			2:00
			66,800	16 : 00		
12	Da Nang	835,700	0		1:32:30	2:00
			83,400	19 : 00		
13	Hue	919,100	0			2:00
			63,600	15 : 15		
14	Dong Ha	982,700	0			2:00
			90,900	20 : 30		
15	Dong Hoi	1,073,600	0			2:00
			77,600	18 : 00		
16	Vung Ang	1,151,200	0			2:00
			58,000	14 : 15		
17	Ha Tinh	1,209,200	0			2:00
			50,000	12 : 45		
18	Vinh	1,259,200	0		1:23:45	2:00
			131,100	28 : 00		
19	Thanh Hoa	1,390,300	0			2:00
			51,700	13 : 00		
20	Ninh Binh	1,442,000	0			2:00
			27,600	8 : 30		
21	Nam Dinh	1,469,600	0			2:00
			25,800	8 : 15		
22	Phu Ly	1,495,400	0			2:00
			46,300	12 : 00		
23	Ngoc Hoi	1,541,700			0:57:00	
				6:03:15	5:08:45	0:42:00

Operating Time	6:03:15	5:08:45
Standing Time	0:42:00	0:08:00
Extra Time	0:29:45	0:03:15
Total	7:15:00	5:20:00

Source: JICA Study Team

5.1.4 Train Section and Number of Trains

(1) Train Section and Passenger Volume

The train section has been set between stations close to depots: Ngoc Hoi – Vinh, Vinh – Da Nang, Da Nang – Nha Trang, Nha Trang – Thu Thiem. In addition to having many passenger movements, depots are close to these stations. Therefore, the operation efficiency of the train set will be higher. The passenger volume between stations are shown in the table below.

Table 5.3: Passenger Volume between Stations (Two-step Case)

Passenger/Day/Round Trip

Section			2030	2040	2050
Ngoc Hoi	–	Phu Ly	36,720	128,249	145,264
Phu Ly	–	Nam Dinh	25,946	112,510	124,415
Nam Dinh	–	Ninh Binh	14,330	108,845	117,304
Ninh Binh	–	Thanh Hoa	13,489	110,173	118,527
Thanh Hoa	–	Vinh	11,416	112,246	119,566
Vinh	–	Ha Tinh	0	121,631	130,586
Ha Tinh	–	Vung Ang	0	116,113	123,496
Vung Ang	–	Dong Hoi	0	113,747	120,458
Dong Hoi	–	Dong Ha	0	116,033	123,076
Dong Ha	–	Hue	0	119,889	127,802
Hue	–	Da Nang	0	119,878	127,709
Da Nang	–	Tam Ky	0	119,922	128,281
Tam Ky	–	Quang Ngai	0	115,573	123,026
Quang Ngai	–	Phu My	0	116,746	124,157
Phu My	–	Dieu Tri	0	115,171	122,898
Dieu Tri	–	Tuy Hoa	0	116,554	124,516
Tuy Hoa	–	Nha Trang	0	123,121	133,096
Nha Trang	–	Thap Cham	16,560	118,009	127,023
Thap Cham	–	Tuy Phong	16,982	118,548	127,639
Tuy Phong	–	Phan Thiet	21,133	123,260	133,277
Phan Thiet	–	Long Thanh	27,357	130,325	141,738
Long Thanh	–	Thu Thiem	37,036	131,453	151,175

Source: JICA Study Team

(2) Number of Trains

In the train section, the number of trains that can correspond to the maximum passenger volume has been calculated. In 2030, the passenger volume will be low, so 10 train sets shall be operated. Although the capacity is 740 people, since the number of passengers varies depending on time, etc., the average boarding ratio is assumed at 70%. In 2040 and 2050, the passenger volume increases significantly. Therefore, 16 train sets shall be operated. The capacity is 1,220 people, and the average boarding ratio is assumed at 70%. In addition to the calculated results, the operation of train sets is also considered. The table below shows the number of trains for each train section.

Table 5.4: Number of Trains by Section (Two-step Case)

	Section	Passenger Volume	Train Set		Number of Trains			Section Length	Train-km
			Number of Cars	Passenger Capacity	Number of Passengers	Culculated Number of Trains	Setting Number of Trains		
		A	B	C	D＝C×0.7	=A/(2×D)	F	G	H＝F×2×G
2030	Ngoc Hoi － Vinh	36,720	10	740	518	35.4	36	282.5	20,340.0
	Vinh － Da Nang								
	Da Nang － Nha Trang								
	Nha Trang － Thu Thiem	37,036	10	740	518	35.7	36	363.4	26,164.8
2040	Ngoc Hoi － Vinh	128,249	16	1220	854	75.1	76	282.5	42,940.0
	Vinh － Da Nang	121,631	16	1220	854	71.2	72	423.5	60,984.0
	Da Nang － Nha Trang	123,121	16	1220	854	72.1	72	472.3	68,011.2
	Nha Trang － Thu Thiem	131,453	16	1220	854	77.0	78	363.4	56,690.4
2050	Ngoc Hoi － Vinh	145,264	16	1220	854	85.0	86	282.5	48,590.0
	Vinh － Da Nang	130,586	16	1220	854	76.5	78	423.5	66,066.0
	Da Nang － Nha Trang	133,096	16	1220	854	77.9	78	472.3	73,678.8
	Nha Trang － Thu Thiem	151,175	16	1220	854	88.5	90	363.4	65,412.0

A: Maximum Passenger Volume by Section (Person/Day/Round-Trip)
B: Number of Cars (Cars/Train)
C: Passenger Capacity of Train (Passenger/Train)
D: Number of Passengers when load factor is 70% (Passenger/Train)
E: Calculated number of train (Number of Trains/Day/One-way)
F: Setting Number of Trains with consideration of Operation of Train Sets (Number of Trains/Day/One-way)
G: Section Length (km)
H: Train-km excluding Deadheading operation between Stations and Depots (km/Day/Round-Trip)

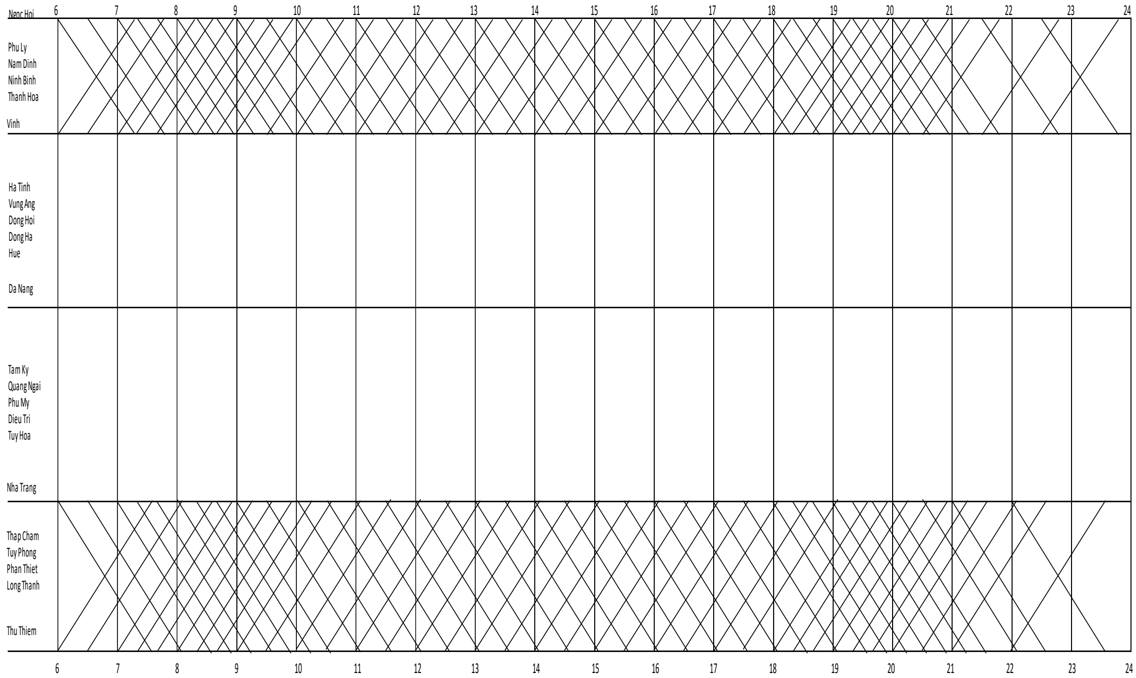
Source: JICA Study Team

5.1.5 Train Schedule and Required Train Sets

Between Ngoc Hoi and Vinh in 2030, 2 trains per hour/ one way is set. Between Nha Trang and Thu Thiem, 2 trains per hour/ one way is also set, but in the morning and evening rush hours, 3 trains per hour will run. For either intervals, no express trains have been set yet. This is because the number of trains is not a lot and the arrival time is short (around 1 hour and 30 minutes).

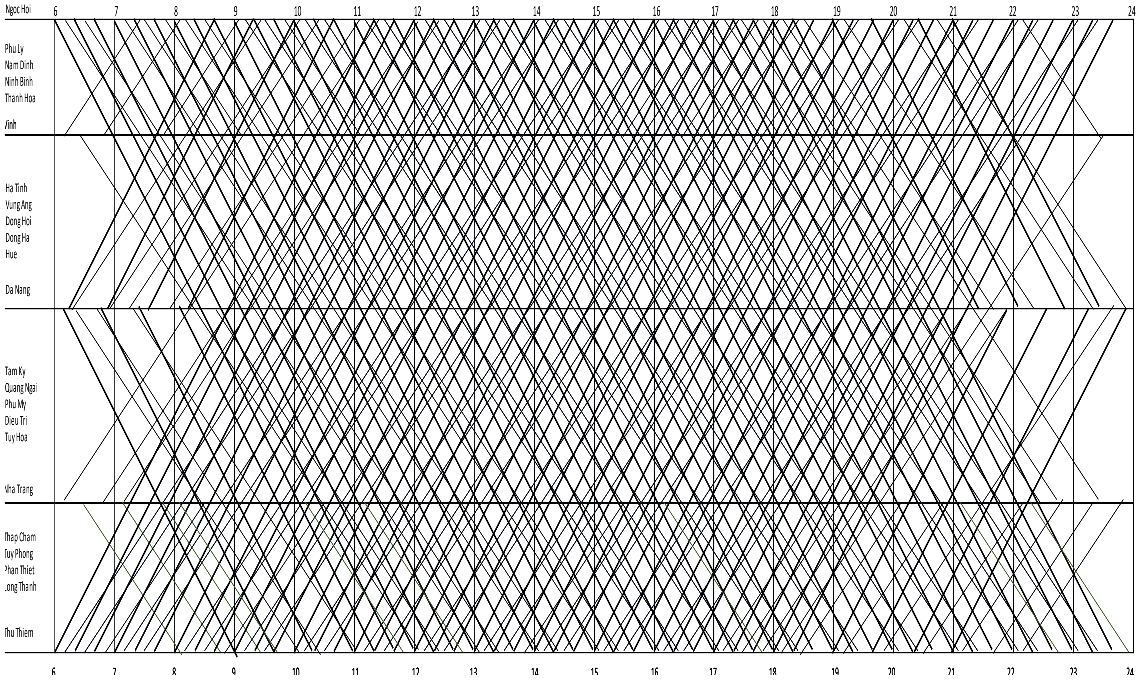
In 2040, the number of trains is assumed to increase significantly, exceeding 70 one way trips per day. Therefore, in addition to local trains, express trains have been set. Although there are some differences depending on the time zone, 3 express trains per hour, 2 local trains per hour have been assumed.

In 2050, the number of trains shall increase even more, reaching 90 one way trips per day. Express trains have been set again, with 3 express trains per hour, 2 local trains per hour assumed.



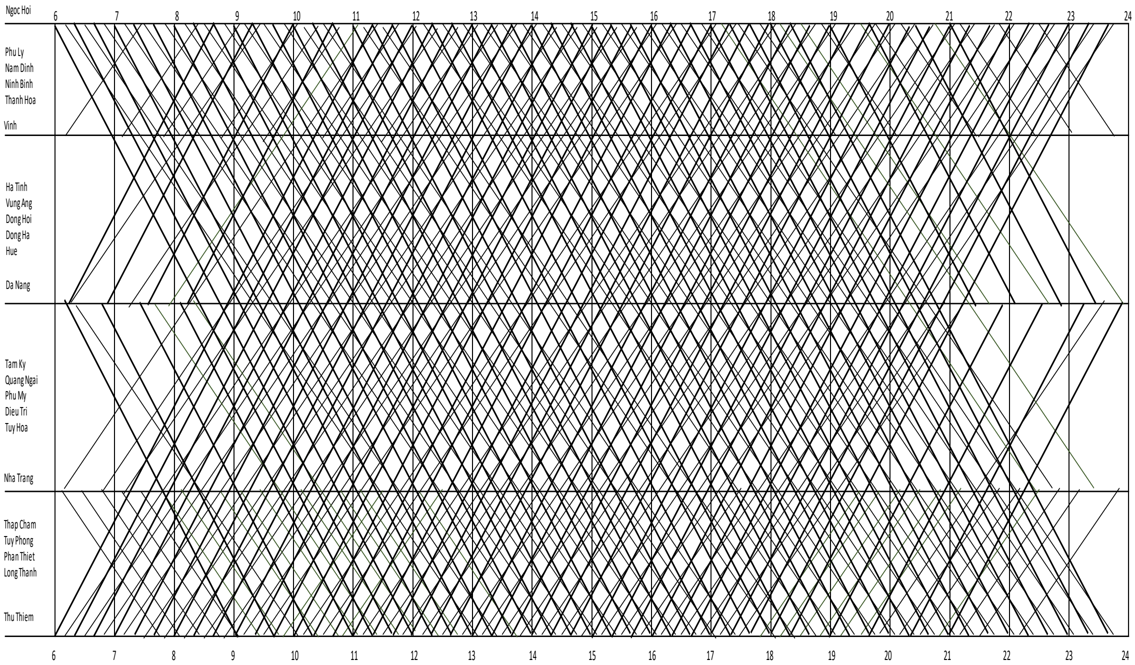
Source: JICA Study Team

Figure 5.2: Train Schedule in 2030



Source: JICA Study Team

Figure 5.3: Train Schedule in 2040



Source: JICA Study Team

Figure 5.4: Train Schedule in 2050

The diagram of the train schedule enables one to count the number of train sets required for the train operation as follows.

1) Since it will take 40 minutes for the first train to arrive and prepare for departure in the opposite direction (returning) in the morning, the trains that are on the track from the night before shall depart first from the departure station. The number of train sets departing before the first arriving train is the number of train sets required at the departure stations.

2) After the arriving trains at the departure stations are prepared to depart in the opposite direction, no more trains are required to stop and wait at the departing stations.

3) If there are trains arriving from intermediate stations, those can be used as returning trains, which means that the required number of train sets at the departure station can be reduced by one. The train departing from intermediate stations shall be stopped at the intermediate stations from the night before.

For efficient operations, the train sets for local trains and express trains are classified separately. During peak periods, reserve train sets shall be on standby to stabilize operations. At least one reserve train set shall be allocated at each depot in the operating section.

Table 5.5: Number of Train Sets per Depot (Two-step Case)

2030	10 vehicles					
	Local	Express	Sub-total	Sub. ×0.1	Reserve	Total
Ngoc Hoi	6	0	6	0.6	1	7
Vinh	6	0	6	0.6	1	7
Da Nang	0	0	0	0	0	0
Nha Trang	7	0	7	0.7	1	8
Thu Thiem	7	0	7	0.7	1	8
Total	26	0	26	2.6	4	30
2040	16 vehicles					
	Local	Express	Sub-total	Sub. ×0.1	Reserve	Total
Ngoc Hoi	9	15	24	2.4	2	26
Vinh	4	0	4	0.4	1	5
Da Nang	8	8	16	1.6	2	18
Nha Trang	7	0	7	0.7	1	8
Thu Thiem	9	15	24	2.4	2	26
Total	37	38	75	7.5	8	83
2050	16 vehicles					
	Local	Express	Sub-total	Sub. ×0.1	Reserve	Total
Ngoc Hoi	11	15	26	2.6	2	28
Vinh	6	0	6	0.6	1	7
Da Nang	6	8	14	1.4	2	16
Nha Trang	16	0	16	1.6	2	18
Thu Thiem	10	15	25	2.5	2	27
Total	49	38	87	8.7	9	96

Note that the table does not include train sets for inspections.
Source: JICA Study Team

5.1.6 Outline of Train Operation Plan (Five-step Case)

(1) Preconditions for Train Operation Planning

HSR's operation plan is formulated on the following assumptions:

1) Operation starts between Long Thanh – Thu Thiem by 2030
2) Operation starts between Ngoc Hoi – Vinh starts by 2040
3) Operation starts between Nha Trang – Long Thanh starts by 2050
4) Operation starts between Da Nang – Nha Trang starts by 2060
5) Operation starts between Vinh – Da Nang starts by 2070
6) Demand is the forecasted amount in this survey for years 2030, 2040, 2050, 2060, and 2070
7) The maximum speed is 320 km/h; the capacity is 370 people for 5 train sets, 740 people for 10 train sets, and 1,220 people for 16 train sets
8) The operating hours have been set to 6:00-24:00

(2) Operating Time Between Stations

Under the above preconditions, the run curve between each station is estimated, as shown in Figure 5.1. Based on the run curve, the estimated operating time between stations is shown in Table 5.1 and Table 5.2. The time required between Ngoc Hoi – Thu Thiem is 7 hours and 15 minutes for the local train and 5 hours and 20 minutes for the express train (including the stoppage time and margin time for various adjustments.)

(3) Required Number of Trains

The number of trains one way/per day is 20 between Long Thanh – Thu Thiem. In 2070, when operation for entire route starts the number of trains will be increased to 106. The passenger volume between stations and the number of trains are shown in Table 5.6 and Table 5.7.

5.1.7 Operation Plan

Local trains (stops at all stations) and express trains (stops only at specific stations to shorten the time to traverse the route) are set as the types of train services. Vinh, Da Nang, Nha Trang, and Long Thanh are set as stations where express trains stop, in consideration of the number of passengers getting on and off trains, availability of depots, schedule of international airport, etc. Until 2050, since the number of trains is small, only local trains are assumed.

Stoppage time at stations are set as 2 minutes for each station. In the actual train schedule, the time required for each train will be changed according to the type station, bypassing trains, etc.

5.1.8 Train Section and Number of Trains

(1) Train Section and Passenger Volume

The train section has been set between stations close to depots: Ngoc Hoi – Vinh, Vinh – Da Nang, Da Nang – Nha Trang, Nha Trang – Thu Thiem. Note that the train section in 2030 are set between Long Thanh and Thu Thiem. In addition to having high passenger movements, depots are also close to these stations. Therefore, the operation efficiency of the train set will be higher. The passenger volume between stations are shown in the table below.

Table 5.6: Passenger Volume between Stations (Five-step Case)

Passenger/Day/Round Trip

Section			2030	2040	2050	2060	2070
Ngoc Hoi	–	Phu Ly	0	46,094	60,594	69,765	166,822
Phu Ly	–	Nam Dinh	0	30,291	39,613	45,519	140,608
Nam Dinh	–	Ninh Binh	0	14,543	19,157	22,014	129,727
Ninh Binh	–	Thanh Hoa	0	12,894	16,810	19,222	130,840
Thanh Hoa	–	Vinh	0	8,738	10,721	11,888	130,772
Vinh	–	Ha Tinh	0	0	0	0	143,655
Ha Tinh	–	Vung Ang	0	0	0	0	134,886
Vung Ang	–	Dong Hoi	0	0	0	0	131,130
Dong Hoi	–	Dong Ha	0	0	0	0	134,141
Dong Ha	–	Hue	0	0	0	0	139,878
Hue	–	Da Nang	0	0	0	0	139,784
Da Nang	–	Tam Ky	0	0	0	20,848	140,789
Tam Ky	–	Quang Ngai	0	0	0	17,253	134,367
Quang Ngai	–	Phu My	0	0	0	20,380	135,481
Phu My	–	Dieu Tri	0	0	0	20,440	134,358
Dieu Tri	–	Tuy Hoa	0	0	0	24,084	136,232
Tuy Hoa	–	Nha Trang	0	0	0	35,036	147,079
Nha Trang	–	Thap Cham	0	0	13,540	36,873	139,989
Thap Cham	–	Tuy Phong	0	0	15,306	37,759	140,710
Tuy Phong	–	Phan Thiet	0	0	21,646	45,622	146,280
Phan Thiet	–	Long Thanh	0	0	31,158	57,416	154,634
Long Thanh	–	Thu Thiem	10,521	14,159	51,652	85,311	181,404

Source: JICA Study Team

(2) Number of Trains

The number of trains that can correspond to the maximum passenger volume has been calculated for each section. In 2030, the passenger volume will be low, so 5 train sets shall be operated. In 2040-2060, 10 train sets will be operated due to the growth of passenger demand. The capacity of 10 train sets is 740 people. In 2070, the passenger volume increases significantly. Therefore, 16 train sets shall be operated. The capacity is 1,220 people. Since the number of passengers vary depending on time, etc., the average boarding ratio is assumed at 70% for each case. In addition to the calculated results, the operation of train sets is also considered. The table below shows the number of trains for each train section.

Table 5.7: Number of Trains by Section (Five-step Case)

	Section			Passenger Volume	Train Set		Number of Trains			Section Length	Train-km
					Number of Cars	Passenger Capacity	Number of Passengers	Calculated Number of Trains	Setting Number of Trains		
				A	B	C	D＝C×0.7	E=A/(2×D)	F	G	H＝F×2×G
2030	Long Thanh	-	Thu Thiem	10,521	5	370	259	20.3	20	36.0	1,440.0
2040	Ngoc Hoi	-	Vinh	46,094	10	740	518	44.5	46	282.5	25,990.0
	Long Thanh	-	Thu Thiem	14,159	5	370	259	27.3	28	36.0	2,016.0
2050	Ngoc Hoi	-	Vinh	60,594	10	740	518	58.5	60	282.5	33,900.0
	Nha Trang	-	Thu Thiem	51,652	10	740	518	49.9	50	363.4	36,340.0
2060	Ngoc Hoi	-	Vinh	69,765	10	740	518	67.3	68	282.5	38,420.0
	Da Nang	-	Nha Trang	35,036	10	740	518	33.8	34	472.3	32,116.4
	Nha Trang	-	Thu Thiem	85,311	10	740	518	82.3	82	363.4	59,597.6
2070	Ngoc Hoi	-	Thu Thiem	181,404	16	1,220	854	106.2	106	1,541.7	326,840.4

A: Maximum Passenger Volume by Section (Person/Day/Round-Trip)
B: Number of Cars (Cars/Train)
C: Passenger Capacity of Train (Passenger/Train)
D: Number of Passengers when load factor is 70% (Passenger/Train)
E: Calculated number of train (Number of Trains/Day/One-way)
F: Setting Number of Trains with consideration of Operation of Train Sets (Number of Trains/Day/One-way)
G: Section Length (km)
H: Train-km excluding Deadheading operation between Stations and Depots (km/Day/Round-Trip)
Source: JICA Study Team

5.1.9 Required Train Sets

The number of required train sets is determined based on the type of train, the turnaround time for a train, and the train inspection plan. In Five-step Case, the operating section is assumed to be expanded every 10 years. Table 5.8 shows the train sets per section. It takes approximately 40 minutes for a train to prepare for the return trip, including the time for passengers' embarking and disembarking. In 2030, the operating section between Long Thanh and Thu Thiem is a very short-haul, so the trains will not need to be cleaned during preparation of the return trip. The cleaning should be done when the train set is alternated with another train set. Therefore, the alternative train set is included in the number of the required train sets in 2030. Also, Table 5.9 shows the number of train sets per railway depot.

Table 5.8: Number of Train Sets per Section (Five-step Case)

	Section			Number of Train Set	Average Service Frequency per Hour	
					Local	Express
2030	Long Thanh	-	Thu Thiem	20	1～2	0
2040	Ngoc Hoi	-	Vinh	46	3	0
	Long Thanh	-	Thu Thiem	28	1～2	0
2050	Ngoc Hoi	-	Vinh	60	4	0
	Nha Trang	-	Thu Thiem	50	3	0
2060	Ngoc Hoi	-	Vinh	68	4	0
	Da Nang	-	Nha Trang	34	1	1
	Nha Trang	-	Thu Thiem	82	2	3
2070	Ngoc Hoi	-	Thu Thiem	106	2	4

Source: JICA Study Team

Table 5.9: Number of Train Sets per Depot (Five-step Case)

2030	Vehicles	Local	Express	Sub-total	Sub. × 0.1	Reserve	Total
Thu Thiem	5	2	0	2	0.2	1	3
Total	-	2	0	2	0.2	1	3
2040	Vehicles	Local	Express	Sub-total	Sub. × 0.1	Reserve	Total
Ngoc Hoi	10	6	0	6	0.6	1	7
Vinh	10	6	0	6	0.6	1	7
Thu Thiem	5	2	0	2	0.2	1	3
Total	-	14	0	14	1.4	3	17
2050	Vehicles	Local	Express	Sub-total	Sub. × 0.1	Reserve	Total
Ngoc Hoi	10	9	0	9	0.9	1	10
Vinh	10	8	0	8	0.8	1	9
Nha Trang	10	8	0	8	0.8	1	9
Thu Thiem	10	9	0	9	0.9	1	10
Total	-	34	0	34	3.4	4	38
2060	Vehicles	Local	Express	Sub-total	Sub. × 0.1	Reserve	Total
Ngoc Hoi	10	10	0	10	1	1	11
Vinh	10	10	0	10	1	1	11
Da Nang	10	8	4	12	1.2	2	14
Nha Trang	10	4	7	11	1.1	2	13
Thu Thiem	10	10	8	18	1.8	2	20
Total	-	42	19	61	6.1	8	69
2070	Vehicles	Local	Express	Sub-total	Sub. × 0.1	Reserve	Total
Ngoc Hoi	16	8	17	25	2.5	3	28
Vinh	16	6	0	6	0.6	1	7
Da Nang	16	9	21	30	3	3	33
Nha Trang	16	8	0	8	0.8	1	9
Thu Thiem	16	9	18	27	2.7	3	30
Total	-	40	56	96	9.6	11	107

No cleaning work at platform is planned for Long Thanh – Thu Thiem operation between 2030 and 2040, instead cleaned train set is used according to the distance operated. After 2040, all the turnback trains are cleaned at platform taking 40 minutes.
Express trains and local trains use their own dedicated vehicles.
Number of trains for inspection is not included.
At least one reserve train is added at each depot.

Source: JICA Study Team

5.2 Maintenance (Ground Facility, Vehicle)

5.2.1 Outline of Shinkansen Maintenance

Maintenance of the railway requires a lot of upkeep and expenses. In the case of Japan, the percentage of maintenance expenses accounts for 40% for ground facilities and 20% for vehicle equipment in total operating expenses. Therefore, conducting efficient maintenance is a major subject in railway management.

(1) Measurement of Track and Electrical Circuits

In order to grasp the condition of the track and electric facility, an inspection train runs about once every ten days on the whole line. The inspection train is called “Doctor Yellow” for Tokaido and Sanyo Shinkansen lines, and “East Eye” for Tohoku and Joetsu Shinkansen lines.

	
Doctor Yellow[1]	East Eye[2]

Figure 5.5: Inspection Trains

The inspection data is processed by SMIS (Shinkansen Management Information System) for Tokaido and Sanyo Shinkansen and COSMOS (Computerized Safety, Maintenance and Operation Systems of Shinkansen) for Tohoku and Joetsu Shinkansen, and used for determining the maintenance work for improving ride comfort, stable current collection, prevention of signal troubles, etc.

(2) Maintenance Procedure

1) Time Slot for Maintenance Work

The maintenance work for Shinkansen begins after the last operational train and finishes before the operation of the first train the next morning, which is different than the conventional lines where the line maintenance is done in-between trains during regular train operation.

2) Procedure for Maintenance Work

The facility commander formulates the maintenance work plan and notifies the relevant bodies. The plan includes the work time zone, the start/end time of the power cut off, the diagrams of the maintenance car and confirmation car.

[1] JR Central, https://railway.jr-central.co.jp/train/work/detail_04_01/index.html (Referenced on 2019.06.10)
[2] JR East, https://www.jreast.co.jp/recruit/student/ebook/maintenance/book.pdf (Referenced on 2019.0610)

3) Time for Maintenance Work

The maintenance work time is split into two sections, in-between stations and the station yard. From the time the last train leaves the section, tracks of both directions are maintained, in the same work-time zone.

4) Start and End of Work Time

The transportation commander is responsible for determining the start time of the maintenance work and for displaying the start time on the operation management system. Upon completion of the work, the facility commander confirms it, then the transportation commander checks and the work time is shifted to the operation time.

5) Control of Maintenance Work

The facility commander controls the maintenance works. Specifically, the commander is responsible for instructing the setting of maintenance work content and work time, approval of start/end time for work, as well as handling abnormal situations.

6) Operation of the Confirmation Car

Before resuming normal operations after the maintenance work is completed, a confirmation car is operated to confirm that there is no abnormality of the railway track, etc.

JR Central R400[3]

Figure 5.6: Confirmation Car

(3) Work Machines

The work machines are shown below.

Long rail transportation car[4]

Ballast carrying car[5]

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[3] Niigata Transys KK, http://www.niigata-transys.com/products/photo02.html (Referenced on 2019.06.10)
[4] Nihonkikaihosen Co. Ltd., http://www.nkh-cjrg.co.jp/business/03_02.html (Referenced on 2019.06.10)
[5] Niigata Transys KK, http://www.niigata-transys.com/products/photo02.html (Referenced on 2019.06.10)

Rail flaw detection car[6]

Rail grinding machine[7]

Tamping machine[8]

Dynamic track stabilizer[9]

Catenary installation vehicle[10]

Tunnel inspection car[11]

Figure 5.7: Work Machines

(4) Progress in Maintenance Technology

The Shinkansen has gained a good reputation from its speed and convenience. However, when operations first got underway, there were noise and vibration problems associated with the high-speed, and countermeasures were required. A lot of the issues were caused by the contact between the rail and the wheel, and the overhead wire and pantographs. These problems were solved with steady technology developments in the field of maintenance. The following is an overview of the progresses made in maintenance technologies.

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6 Nihonkikaihosen Co. Ltd., http://www.nkh-cjrg.co.jp/business/03_02.html (Referenced on 2019.06.10)
7 Same as above
8 Same as above
9 Same as above
10 JR West, https://www.westjr.co.jp/fan/car/ (Referenced on 2019.06.10)
11 Same as above

1) Rails and Wheels

The force to move the train occurs via the adhesive force between the rail and the wheels. The adhesive force is the product of the vertical force exerted from the wheel to the rail due to gravity and the coefficient of friction between the two; the coefficient of friction decreases with the increase in speed.

When the Shinkansen was initially developed, it was thought that the speed of a wheel-rail system is limited to about 250-300 km/h, due to the decreasing adhesive strength and air resistance, etc. This is one of the reasons why the Institute of Railway Technology started researching MAGLEV technology two years prior to the opening of the Shinkansen. However, fine-tuning the control of wheel turning force became possible, and now, there is no doubt that a wheel-rail system can operate at 300-350 km/h.

The noise and vibration becomes a large issue when the wheel is not a perfect circle as well as when the rail is not smooth. When brakes are applied to the train, the wheels slide on the rails and wears down parts of the wheel, these worn areas or “flats” that form on the wheels also damage the rails. Wear and tear on the rails and wheels cause further damage to each other, and the problem gets even bigger. The current solution is to correct the wheel at the time of vehicle inspection to make it a perfect circle, and to grind the rail surface by during maintenance work.

2) Overhead Contact Wire and Pantograph

The overhead line and pantograph also produce friction noise unless smooth. In addition, when the pantograph loses contact from the overhead line, an electric arc is generated, and it damages both the pantograph and the overhead line. Originally, the Shinkansen had many pantographs (one for two cars), and when a front pantograph shook the overhead line, this damaged the pantograph behind it.

The solution was to reduce the number of pantographs and connect them with a high-pressure bus bar on the vehicle. As the number of pantographs were decreased, the aerodynamic noises decreased. Further, since the pantographs are connected by the bus, even if one pantograph loses contact, the voltage of the pantograph and wire remains the same, and therefore, no arc occurs. By reducing the interaction between overhead lines and pantographs, their lifespans have been extended, and the noise has been reduced, which greatly alleviated these issues.

3) Component and Material

In addition to the above, improvements were made to the components and materials of vehicles, tracks, and power equipment that make up the railway. These are shown in the following table.

Table 5.10: Improvement of Component and Material

Field	Item
Car	Aluminum body, AC induction motor, VVVF inverter, Auxiliary power supply unit, High-frequency induction hardening axle, Sealed bearing, Unit brake, Regenerative brake, Abrasion-resistant brake material, Carbon-based contact strip, a High voltage bus bar (decrease pantographs)
Track	Long rail, Slab track, Head hardened rail, Elastic sleeper on ballast track, Synthetic sleeper
Power	High tension overhead wire structure, Wear-proof trolley wire

Source: R&D on Railway Maintenance - Present and Future, Railway Technical Research Institute 2008

(5) Future Directions and Recommendations

Future advancement of maintenance includes the following.

1) Advancement of Preventive Maintenance

In the early stage of the railway, the mainstream for maintenance was the "post-maintenance method," where equipment and parts are repaired when damage is found. With the accumulation of knowledge, maintenance has been transitioning to a "periodic repair system," where periodic inspections, replacements and repairs are conducted on parts that may be malfunctioning. Recently, the "preventive maintenance method" has become the mainstream for maintenance, where signs of deterioration are detected early, and countermeasures are taken accordingly.

In the future, maintenance should progress to improve the accuracy of prediction and reduction of the life cycle cost, and consideration of the risks of deterioration.

2) Elucidation of Boundary Issues

In railways, there are many components that affect and (at times) damage each other, such as the wheels and rails, overhead lines and pantographs, and wheels and brakes. In the future, the fundamental mechanisms of deterioration and damage need to be examined and tackled, to reduce total costs including the counterpart components. Ultimately, optimality shall be sought after as a railway project beyond the framework of each technical field.

3) Automation of Inspection and Labor-Saving Methodologies

In response to human labor shortages and human errors, automation and labor-saving methodologies are required. For this reason, it is required to incorporate the results of new technological developments on inspection methods and repair methods.

4) Recommendation towards Vietnam HSR

Maintenance in the early days of the Shinkansen was based on the experience of conventional railways. However, there were many problems as mentioned above, and gradually, the current system has been established through steady technology development.

When planning the maintenance system for the Vietnam HSR, it is important to recognize that the conventional railway and the high-speed railway are completely different systems. The first step is to adopt the maintenance system that is being carried out on the Shinkansen and to establish it towards the Vietnam HSR.

Then, improvements should be made from on-site experience and studying examples in other countries.

5.2.2 Shinkansen Track Maintenance

For the Tokaido Shinkansen, a ballast track was fully adopted. The reason for this was because, at that time, alternative tracks were not put into practical use, and the construction cost was low.

After the start of operation, it was found that track destruction rapidly progressed from the operation of the high-speed train, which lead to the development and practical application of the slab track being rapidly advanced as the new track structure. Since 1960, the adoption of the slab track became the principle. On the other hand, for sections where application of the slab track is difficult, an improved ballast trajectory has been applied.

(1) Ballast Track of the Shinkansen

The characteristics of the improved ballast track are as follows, comparing the previous ballast type with the improved ballast type.

Table 5.11: Comparison of Ballast Track

Item	Previous type			Improved type			Note
	Soil structure	Tunnel	Viaduct	Soil structure	Tunnel	Viaduct	
Rail	60 kg			60 kg			
Tie pad	90 t/cm			60 t/cm			Reduction of spring constant
Ballast mat	-	-	-	-	Install	Install	
PC sleeper	3T or 4T (W = 280 mm, D = 190 mm)			3H (W = 310 mm, D = 220 mm)			To increase elasticity
Ballast thickness (mm)	300	250	200	300	250	200	

Source: "Track structure of the nationwide Shinkansen network" (Magazine Railway Track, January 1973)

The main feature of the improved ballast track was to make the entire track structure soft and to suppress the unevenness of the rail surface. This supports the reduction of the large wheel load along with the reduction of unsuspended mass. The improvements are listed below.

- Reduction of rail support spring constant
  - Decrease in the spring constant of the tie pad
  - Increase in the elasticity of sleepers
  - Insert a rubber plate between sleepers and road floor
  - Apply moderate elasticity to the trackbed
    (Prevention of ballast deterioration by controlling the size and quality of ballast)

- Suppression of short wavelength track deviation such as unevenness of rail surface roughness
  - Improvement of completion accuracy of welded seams
  - Improvement of completion accuracy (tolerance) during rail production

(2) The Transition of the Track Structure

The track structure of the Shinkansen has gradually shifted to the slab track. This is shown in the table below.

Table 5.12: Track Structure of Shinkansen

Line length (km)

	Ballast track				Slab track	Total	Opening year
	Tunnel	Viaduct	Soil structure	Total			
Tokaido (Tokyo - Osaka)	69	173	274	516 (100%)	0	519 (100%)	1964
Sanyo (Osaka - Okayama)	47	89	12	148 (90%)	16 (10%)	164 (100%)	1972
Sanyo (Okayama - Hakata)	10	62	54	126 (32%)	272 (68%)	398 (100%)	1975
Tohoku (Tokyo - Morioka)	0	85	7	92 (19%)	406 (81%)	498 (100%)	1982

Source: Railways of the World (JARTS, 2015)

The following table shows the track structure of the Tohoku Shinkansen.

Table 5.13: Track Structure and Applied Line of the Tohoku Shinkansen (Tokyo - Morioka)

		Mainline		Other line	
		Main track	Passing track	Dead-heading	Arrival/Departure track
Rail		60 kg Long (R>800 m) Standard (R<800 m)	60 kg Long rail or Standard rail		More than 50 kg
Slab /Sleeper		Slab or PC3H 43/25 m	Slab or PC3T or PC4T 42/25 m		RC39+W1 /25 m
Rail joint		Expansion joint (R≥1,000 m) Glued-insulated joint (Standard rail section or Supported joint)	Simple expansion joint or Glued-insulated joint or Supported joint		Supported joint
Rail fastening	Slab	Direct type 4 or type 5			
	Ballast	60 kg high-speed type 60G large scale sleeper	102 Improved type 60G for large-scale sleeper		RC103 Improved type F type, 50H for large-scale sleeper
Ballast depth	Earthwork	Crushed stone more than 300 mm		Crushed stone more than 200 mm	
	Tunnel	more than 250 mm			
	Viaduct	more than 200 mm			
Ballast mat		Ballast mat for tunnel or viaduct type		-	

Source: "Track construction of the Tohoku Shinkansen" (Magazine Railway Track, January 1974)

(3) Profitability of the Slab Track

The slab track is less maintenance-intensive, so the track repair cost is only 25% of that for the ballast track. Construction costs are high, but the investment amount can be recovered in about 4 years.

The below table shows the economic calculation of a slab track. It should be noted that this is a comparison between the slab and the ballast track on a viaduct, and not the contrast of the soil structure and viaduct.

Table 5.14: Economic Calculation of Slab Track

Item	Unit	Ballast A	Slab B	Comparison	Note
Construction cost	Thousand yen / km	30,000	58,000	B-A=28,000	28,000/6,985 =4.0
Maintenance personnel	Person / km	0.83	0.41	B/A=0.50	
1) Annual expenses	Thousand yen / km	13,807	6,822	B-A=-6,985	=2) + 5)
2) Ordinary expenses	-	12,347	3,592	=-8,755	=3) + 4)
3) Salary	-	1,835	906	=-929	
4) Repair costs	-	10,512	2,686	=-7,826	
5) Capital cost	-	1,460	3,230	= 1,770	=6) + 7)
6) Amortization cost	-	290	960	670	
7) Interest	-	1,170	2,270	1,100	

Source: "Track structure of Sanyo Shinkansen Okayama - Hakata" (Magazine Railway Track, February 1975)

The proportion of slab and ballast tracks of the Tohoku Shinkansen (Tokyo – Morioka) are as follows.

Table 5.15: The Proportion of Slab and Ballast Track of Tohoku Shinkansen (Tokyo – Morioka)

		Slab track A	Ballast track B	Total C	Slab ratio(A/C)
Tunnel		110 km	0 km	110 km	100%
Viaduct, Bridge		257 km	85 km	342 km	75%
Soil structure	Ordinary	0 km	7 km	7 km	0%
	Special	39 km	0 km	39 km	100%
Total		406 km	92 km	498 km	82%

Source: "Track construction of the Tohoku Shinkansen (Tokyo Morioka)" (Magazine Railway Track, January 1974)

Even in the viaduct/ bridge section, the ballast track is 85 km. This is due to the weak ground and the unique nature of the adjacent structures. Although the ordinary soil structure section is very short, ballast track is adopted for all.

5.2.3 Rolling Stock

(1) Outline of Rolling Stock Inspection

1) Concept of Rolling Stock Inspection and Maintenance

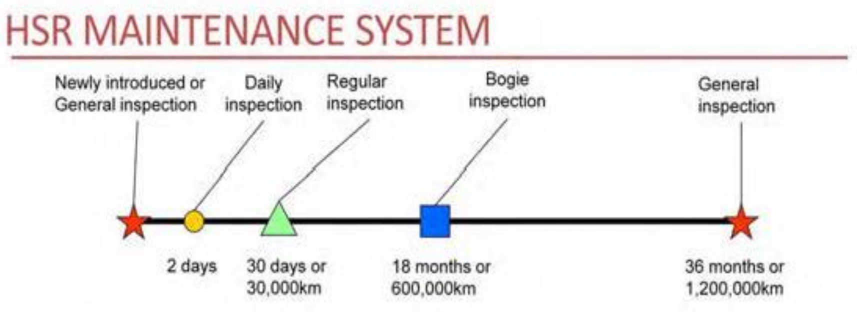
Railway rolling stock operates on a daily basis to transport passengers. Therefore, it is inevitable that deterioration occurs. However, by performing appropriate inspection and maintenance, it is possible to extend the life of the rolling stock while maintaining the performance and function as the time it was manufactured.

Furthermore, by maintaining the condition of the rolling stock, accidents and traffic inhibitions can be minimized, and high service levels can be maintained.

Daily inspections of the rolling stock are carried out at the train operation depot responsible for the operation of the rolling stock. Large-scale inspections and maintenance (other than daily inspections), preventive inspections and repairs are conducted at a well-equipped rolling stock workshop. Nowadays, it tends to handle all inspections as a comprehensive zone that is advantageous for rolling stock operation and others.

2) Types of Rolling Stock Inspections

Rolling stock is composed of various complex devices and parts. Since there are differences in the lifetime, running kilometers and periods until repairs are conducted, each device/part is managed separately depending on service life. The maintenance system for HSR is shown in the below Figure.



Inspection	Period	Contents
Daily Inspection	Within 2days	Brief inspection of equipments Supplement or replacement of consumables
Regular Inspection	Within 30 days or 30,000km	Inspection to check conditions and motions of mechanical and electrical equipments
Bogie Inspection	Within 18 months or 600,000km	Inspection of important parts of bogie
General Inspection	Within 36 months or 1,200,000km	Detail inspection of whole car body and equipments

Source: Previous Study (JICA, 2013)

Figure 5.8: Maintenance System for Rolling Stock of High-Speed Railway

3) Type of Rolling Stock

The type of vehicle planned for introduction at the start of operation is assumed to be E5 series used at JR East in Japan. The rolling stock specifications are shown in the below table.

Table 5.16: Type of Rolling Stock

Items		Specifications
Car length	Lead car	26,250 mm
	Intermediate car	25,000 mm
Width of car		3,350 mm
Height of car		3,650 mm
Distance between two bogies		17,500 mm
Number of a cars per train		16 cars
Length of a train set		402,500 mm
Axle load		13.1 ton

Source: JR East E5 system (leading vehicle for mass production) (Magazine Vehicle Technology No. 239, 2010)

(2) Contents of Rolling Stock Inspection

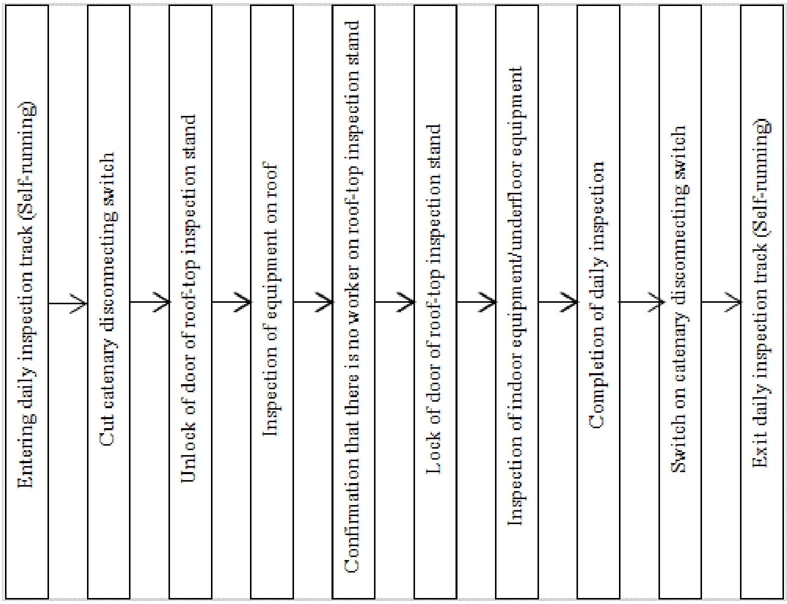
The workshops for the high-speed railway are assumed to be at two locations, Hanoi and Ho Chi Minh City and each workshop is planned to be responsible for the same number of train sets.[12]

1) Daily Inspection

Daily inspections shall be conducted in a cycle of 48 hours, as shown in Figure 5.9. The works shall be conducted during the overnight stay of a rolling stock to improve the operational efficiency. The ATC operation inspection and cleaning work are carried out concurrently with the

[12] Each is responsible for 51 train sets.

daily inspection. The time required for inspection of one train set is one hour. A service deck is provided at the daily inspection track.



Source: JICA Study Team

Figure 5.9: Standard Workflow of Daily Inspection

- Working Hours
  The working hours shall be 10 hours, from 08:00PM in the evening until 06:00AM in the next morning.

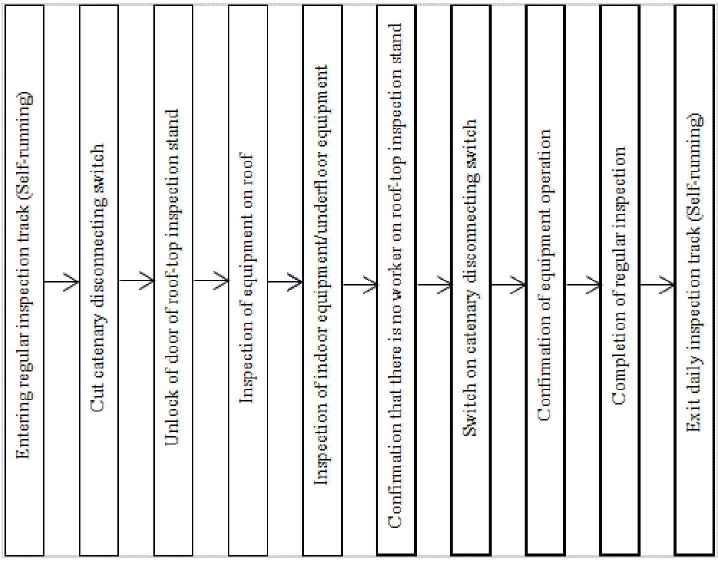
- Daily Inspection Track
  From the viewpoint of the inspection cycle and examination time, three tracks are sufficient for the daily inspection track.

2) Regular Inspection

The cycle of regular inspection is within 30 days or within 30,000 km, as shown in Figure 5.10. Non-dismantling inspection and repair of parts are carried out throughout the entire train.

Confirmation is made on whether each equipment part is complete by conducting disassembly inspections etc. Also, ATC characteristic inspections and inspection of the axle with ultrasonic wave flaw detection are conducted.

Many workshops have service decks that can be used in conjunction with the daily inspections. The regular inspection, (which takes half a day during daytime) is conducted in operation intervals to increase the efficiency of the rolling stock usage.



Source: JICA Study Team

Figure 5.10: Standard Workflow of Regular Inspections

- Annual Entry Frequency
  The number of entrance frequency per year for one train set is 30.

- Number of Train Sets for Regular Inspections
  The number of train sets for regular inspection each day is 8 train sets.

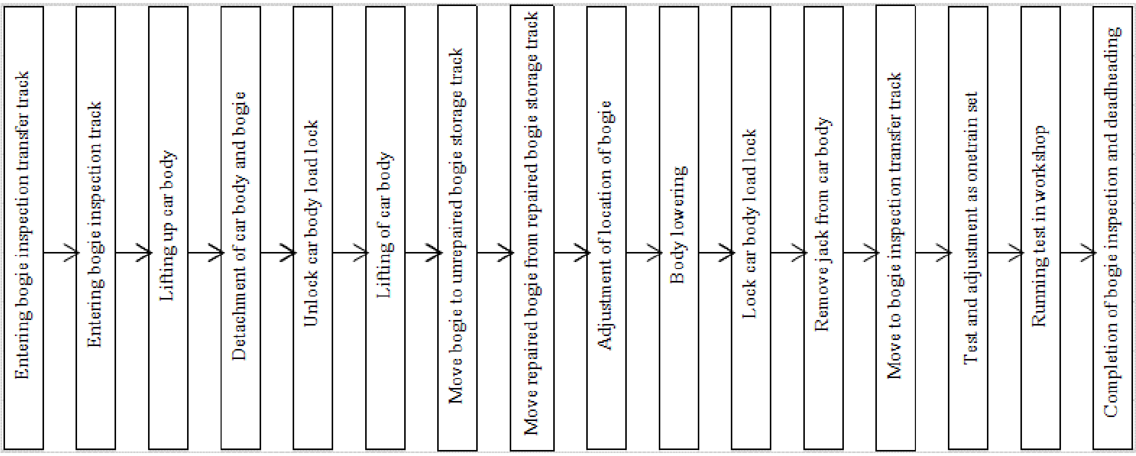
- Number of Tracks for Regular Inspections
  The number of tracks for regular inspection is 4.

3) Bogie Inspection

The bogie inspection is carried out by disassembling the bogie, the main electric motor, and the wheel shaft.

The bogie inspection is conducted within 1.5 years or 600,000 km. The below figure shows the standard workflow of the bogie inspection.

In Japan, the bogie inspection is conducted by replacing the bogies that have been inspected already to improve operational efficiency and to reduce the idle time for detailed inspection.



Source: JICA Study Team

Figure 5.11: Standard Workflow of Bogie Inspection

- Planning of Bogie Inspection
  A semi-comprehensive (8-car) batch replacement method shall be adopted, in order to reduce the number of spare bogies. Thus, 16 spare bogies shall be equipped.

- Number of Cars for Bogie Inspections
  The number of bogie inspections is the same as the number of general inspections.

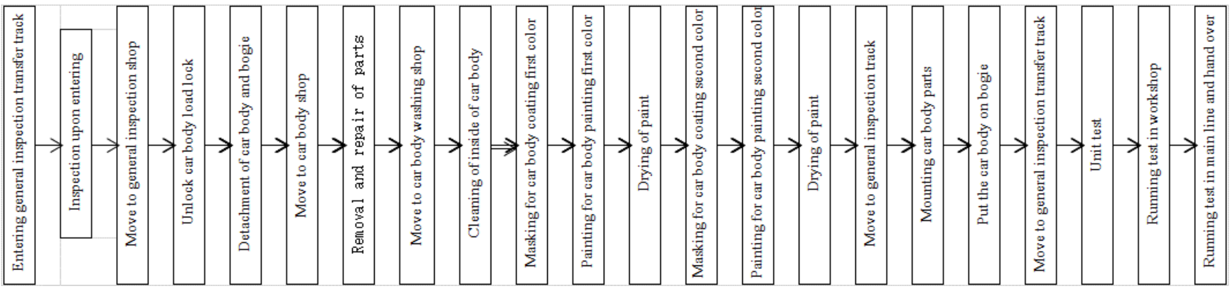
4) General Inspection

In the general inspection, the car is disassembled, and all the equipment and parts are inspected. The inspection is conducted for each train set (16-car) as a unit.

- Number of Train Set Inspected
  The entry frequency is determined by the traveling distance. Annually, 47 train sets enter with an entry interval of 5 days.

- Standard Workflow of the General Inspection
  The below figure shows the standard workflow of the general inspection. The number of days at the workshop, from the entry of the train set to the delivery to the operation division, is planned as 15 days.

- The Scale of the Workshop
  The number of cars at the dismounting/mounting tracks simultaneously is assumed at 34 per day.

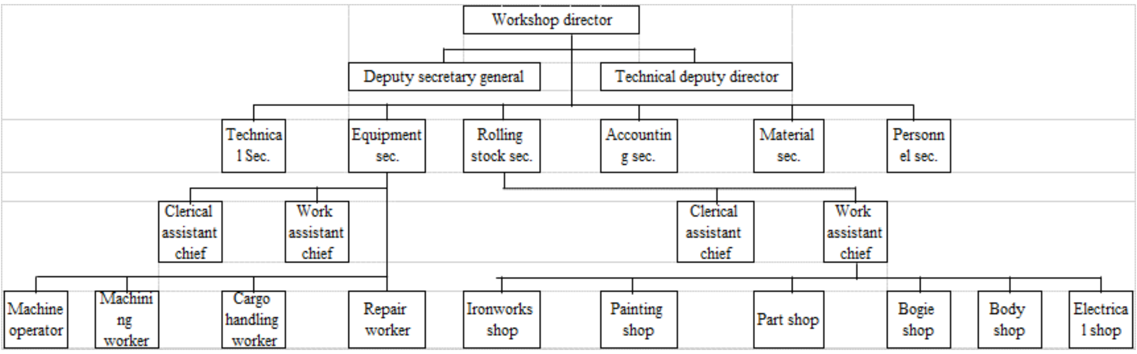


Source: JICA Study Team

Figure 5.12: Standard Workflow of the General Inspection

(3) Organization, Staff, Allocation of Workshop

The organization of the workshop is shown in the below figure.



Source: JICA Study Team

Figure 5.13: Workshop Organization

The work area for each workplace is shown in the below table.

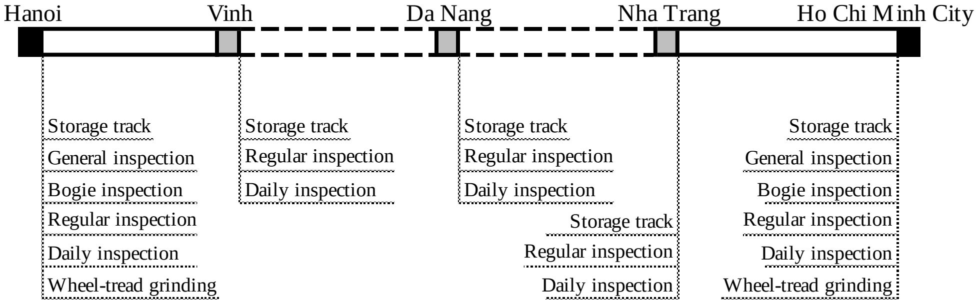
Table 5.17: Work Area of Workshop

Workplace		Work Area (m^2)
1	Daily inspection track	27 × 414 × 3 = 11,178 (3 tracks)
	Cleaning track	
2	Regular inspection shed	36 × 414 = 14,904 (4 tracks)
3	Track and catenary inspection car shed	18 × 50 = 900
4	Wheel-tread grinding shed	17 × 50 + 8 × 40 = 1,170
	Total	
5	Bogie transfer track	18 × 206 = 3,708
6	Bogie inspection track	9 × 414 = 3,726
7	General inspection track	18 × 414 = 7,452
8	Car body lifting and loading	20 × 36 = 720
9	Body inspection shed	20 × 170 + 33 × 168 = 8,944
10	Body painting shed	12 × 36 + 12 × 90 = 1,512
11	Car parts inspection shed	60 × 206 = 12,360
12	Non-revenue train shed	35 × 100 + 8 × 50 = 3,900
	Car body & bogie assembly shed	
13	Material storehouse	20 × 35 = 700
14	Dangerous goods storehouse	10 × 20 = 200
15	Paint formulation site	10 × 10 = 100
16	Dust processing plant	20 × 20 = 400
17	Sewage treatment plant	10 × 20 = 200
18	Power room	20 × 20 = 400
19	Guard room	10 × 5 + 20 × 5 = 150
20	Garage	8 × 20 = 160
21	Office / conference room	
22	Dressing room / bath	
	Total area	72,784
	Indirect staff	
	Total staff	

Source: JICA Study Team

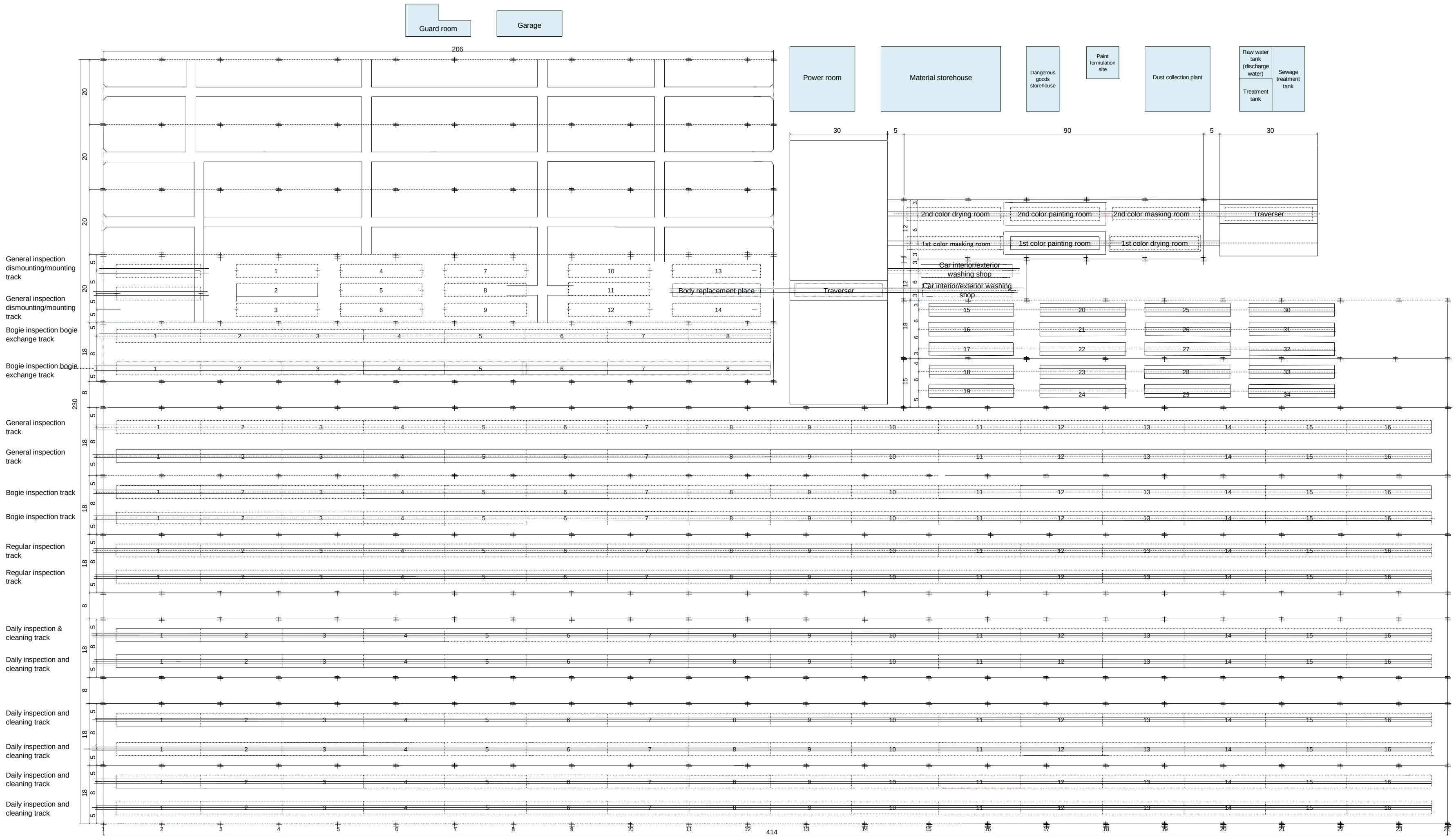
(4) Workshop Plan

The location and schematic layouts of the workshop are shown in the below figures.



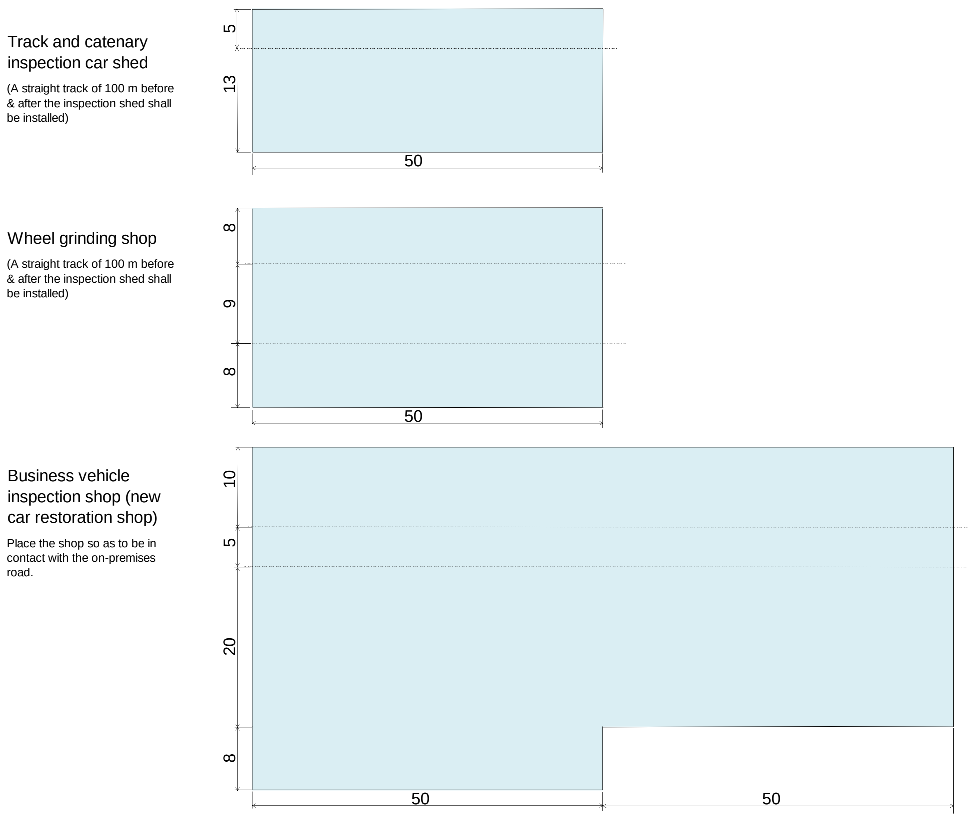
Source: JICA Study Team

Figure 5.14: Location of Workshops and Depots



Source: JICA Study Team

Figure 5.15: Schematic Layout of Workshop (1 of 2)



Note: The three buildings above should be installed in the appropriate location in the depot.
Source: JICA Study Team

Figure 5.15: Schematic Layout of Workshop (2 of 2)

5.3 Operation and Management Organization

The operation and management of HSR shall be carried out by the control offices, which are the head office, the north branch office and the south branch office, as well as by the field offices. The preconditions for considering the railway organization and personnel, including the number of train sets, railway equipment and facilities are described in below in section 5.3.1. The calculated results of the employees and organization are outlined in 5.3.2, and the organizational structures in 5.3.3 and 5.3.4. Lastly, the operation and management organization necessary for Five-step Case is described in 5.3.5.

5.3.1 Preconditions

The number of train sets, railway structure and track structure of the HSR, which are the preconditions for considering the railway organization, are shown in Table 5.18, Table 5.19, and Table 5.20. The railway equipment and facilities are assumed as follows.

- Rolling stock: Designed on the basis of series E5
- Security/signal systems: CTC and ATC
- Electrification of equipment/facilities: AC 25,000 V

Table 5.18: Number of Train Sets for 2030, 2040 and 2050

Section	Year 2030	Year 2040	Year 2050	Remarks
Ngoc Hoi – Vinh	*36	**76	**86	Train operation time from 6:00 to 24:00
Nha Trang – Thu Thiem	*36	**72	** 90	
Ngoc Hoi – Thu Thiem	--	**72	** 78	

Note: * 10-car trains, **16-car trains
Source: JICA Study Team

Table 5.19: Railway Structure of Vietnam HSR

Section	No. of Sta.	Railway Structure (km)				
		Fill	Cut	Viaduct Bridge	Tunnel	Total
Ngoc Hoi – Vinh	6	26.6	11.9	226.1	11.0	275.6
Vinh – Nha Trang	11	187.4	95.1	463.2	135.6	881.2
Nha Trang – Thu Thiem	6	73.2	62.6	196.3	31.8	363.9
Ngoc Hoi – Thu Thiem	23	287.2	169.5	885.6	178.5	1,520.7

Source: the local consultants

Assuming that the ballast structure is applied to the earth structure of the cut and fill, and the slab structure is applied for others, the track structure is summarized as follows.

Table 5.20: Track Structure of HSR

Section	Track Structure (km)				
	Ballast Track		Slab Track		Total
Ngoc Hoi – Vinh	38.5	14.0%	237.2	86.0%	275.6
Vinh – Nha Trang	282.5	32.1%	598.8	67.9%	881.2
Nha Trang – Thu Thiem	135.8	37.3%	228.1	62.7%	363.9
Ngoc Hoi – Thu Thiem	456.7	30.0%	1,064.0	70.0%	1,520.7

Source: JICA Study Team

The works of the head office and branch offices, as well as the field offices, are assumed as follows, with reference to examples in Japan.

(i) In principle, related maintenance shall be carried out under the direct work, including the field operations. However, some works such as rolling stock cleaning, visual inspection of overhead contact line, and cleaning of insulators shall be outsourced.
(ii) The annual number of employees assumed for the head office and branch offices shall remain unchanged irrespective of the increase in the number of trains.
(iii) The amount of staff for a station are calculated reflecting the station size, and ticket sale/ ticket gate staff depends on the increase of passengers.
(iv) The amount of staff related to rolling stock are calculated by the repair schedule on the basis of the deployment of HSR cars.

5.3.2 Calculation of the Number of Employees

The number of employees for each office are assumed as follows, in reference to Japan's experience.

Table 5.21: Number of Employees for HSR for 2030, 2040 and 2050

Organization		2030	2040	2050
Head Office		173	173	173
Hanoi Branch Office	Control division	194	194	194
	Field offices	1,944	6,043	6,339
	Total	2,138	6,237	6,533
HTMC Branch Office	Control division	194	194	194
	Field offices	2,325	6,088	6,385
	Total	2,519	6,282	6,579
Total		4,830	12,691	13,285

Source: JICA Study Team

5.3.3 Organizational Structure and Employees for Control Offices (Head Office, Branch Offices, Operation Control Center)

The organization and staff of the head office are assumed as follows.

Table 5.22: Organization and the Number of Employees for the Head Office, Vietnamese HSR Managing Company

Name of Division/Section		Principal Assignment	Number of Employees
Management Planning Division	Planning Section	Management planning	6
	Investment Planning Section	General coordination on the investment into equipment/facilities	10
	Subtotal		16
Safety and Emergency Management Office		Planning and general coordination on safety/disaster countermeasures	8
Education/Training Office		Planning of employee education and training center	8
General and Personnel Affairs Division	General Affairs Section	Control of internal services and general affairs, public relations and legal affairs	10
	Personnel Affairs Section	Planning of the number of employees, personnel affairs and rotation, rewards and punishment	15
	Welfare Section	Health and welfare of employees	6
	Subtotal		31
Financial Affairs/Materials Division	Accounting Section	Budget control, cash receipt and payment	15
	Accounts Section	Accounting procedures, settlements	20
	Materials Section	Material service	10
	Subtotal		45
Railway Operations Headquarters	Control Section	Control of internal services, general affairs	5
	Marketing Section	Planning of marketing, station services and ticket selling	6
	Transportation and Rotation Section	Train operation planning rotation of crews and rolling stock, instruction for crews	10
	Rolling Stock Section	Planning the inspection and repair of rolling stock	6
	Equipment/Facilities Section	Maintenance of tracks and structures	10

Name of Division/Section		Principal Assignment	Number of Employees
	Electricity Section	Maintenance of power supply and signal/telecommunication equipment/facilities	10
	Subtotal		47
Information System Office		Maintenance/Installation of information systems	8
Training Center		Implementation of education/skill training of employees in different fields	10
Total			173

Source: JICA Study Team

The organization and staff of the Branch Offices are assumed as follows.

Table 5.23: Organization and the Number of Employees for Branch Offices, Vietnamese HSR Managing Company (Hanoi Branch Office and HCMC Branch Office)

Name of Division/Section		Principal Assignment	Number of Employees
Safety and Emergency Management Office		Planning and general coordination on safety/disaster countermeasures	6
Education/Training Office		Planning of employee education and education/training at VR Vocational Colleges	6
Control Division	General Affairs Section	Control of internal services and general affairs, public relations and legal affairs	10
	Personnel Affairs Section	Planning of the number of employees, personnel affairs and rotation, reward and punishment, health and welfare of employees	15
	Financial Affairs Section	Budget control, cash receipt and payment, accounting procedures, settlements	20
	Material Section	Material services	10
	Subtotal		55
Transport, Rolling Stock and Marketing Division	Control Section	Control of internal services, general affairs	5
	Marketing Section	Planning of marketing, station services and ticket selling	5
	Transportation and Rotation Section	Train operation planning, rotation of crews and rolling stock, instruction for crews	10
	Rolling Stock Section	Planning inspections and repairs of rolling stock	10
	Subtotal		30
Equipment and Facilities Division	Control Section	Control of internal services, general affairs	5
	Track Maintenance Section	Maintenance of tracks	10
	Equipment/Facilities Section	Maintenance structures and architecture	10
	Subtotal		25

Name of Division/Section		Principal Assignment	Number of Employees
Electricity Division	Control Section	Control of internal services, general affairs	5
	Power Supply Section	Maintenance of power supply equipment/facilities	10
	Signal/Telecommunication Section	Maintenance of signal/telecommunication equipment/facilities	10
	Information System Section	Maintenance of information systems	6
	Subtotal		31
Operation Control Center (OCC)		Dispatching services for HSR Train operation control	41
Total			194

Source: JICA Study Team

The Operation Control Center manages the HSR operation. The number of dispatchers is assumed as follows.

Table 5.24: Number of Employees at the Operation Control Center (OCC) (Same for Hanoi Branch and HCMC Branch)

Assignment	Assigned number	Required number	Remarks
Chief dispatcher and Assistant Chief Dispatcher	2	7	Each dispatcher is assumed to work for 24 hours under a one-shift system.
Transport dispatcher	3	11	
Passenger dispatcher	1	4	
Rolling stock and crew dispatcher	2	7	
Equipment/facilities dispatcher	1	4	
Power supply dispatcher	1	4	
Signal/communication system dispatcher	1	4	
Total	11	41	

Source: JICA Study Team

5.3.4 Organizational Structure and Employees of Field Offices

Stations, driver/conductor depot, rolling stock inspection base, rolling stock workshop, track maintenance depot, power supply station depot, signaling/telecommunications depot, and material center are assumed to be placed as field offices. The number of employees is assumed as follows.

Table 5.25: Number of Employees at Field Offices

Organization		Number		Number of employees		
		2030	2040	2030	2040	2050
Hanoi Branch Office	Station	6	12	357	942	1,029
	Driver/Conductor-depot	2	3	131	654	723
	Rolling stock Inspection Base	1	3	38	158	196
	Rolling Stock Workshop	1	1	318	1,150	1,252
	Track maintenance-depot	3	6	429	1,299	1,299
	Power Supply Station-depot	3	6	337	990	990
	Signaling/Telecommunications-depot	3	6	284	750	750
	Material Center	2	4	50	100	100
	Total	21	41	1,944	6,043	6,339

Organization		Number		Number of employees		
		2030	2040	2030	2040	2050
HCMC Branch Office	Station	6	11	371	789	868
	Driver/Conductor-depot	2	2	156	687	765
	Rolling stock Inspection Base	1	2	38	118	156
	Rolling Stock Workshop	1	1	318	1,150	1,252
	Track maintenance-depot	3	6	595	1,411	1,411
	Power Supply Station-depot	3	6	435	1,046	1,046
	Signaling/Telecommunications-depot	3	6	362	792	792
	Material Center	2	4	50	95	95
	Total	21	38	2,325	6,088	6,385
Total	Station	12	23	728	1,731	1,897
	Driver/Conductor-depot	4	5	287	1,341	1,488
	Rolling stock Inspection Base	2	5	76	276	352
	Rolling Stock Workshop	2	2	636	2,300	2,504
	Track maintenance-depot	6	12	1,024	2,710	2,710
	Power Supply Station-depot	6	12	772	2,036	2,036
	Signaling/Telecommunications-depot	6	12	646	1,542	1,542
	Material Center	4	8	100	195	195
	Total	42	79	4,269	12,131	12,724

Source: JICA Study Team

(1) Station

- Assignment – Ticket issuance, entrance/exit gate, platform train operation, passenger guidance etc.
- Calculation method for number of employees:
  - (i) Managers and administrators are calculated based on station scale, which is classified into six patterns of; A (40,000 or more entrained passengers/day), B (40,000-25,000 entrained passengers/day), C (25,000-15,000 entrained passengers/day), D (15,000-5,000 entrained passengers/day), E (5,000-2,500 entrained passengers/day) and F (2,500 or less entrained passengers/day)
  - (ii) Platform staff are calculated based on equipment conditions and train stop numbers at the platform.
  - (iii) Ticket sale and ticket gate staff are calculated based on the number of passengers at each station.

- Organizational Structure:

Station Manager
- Station Sub-Manager
- Assistant Station Manager
- Assistant Station Manager, Station Affairs
- Assistant Station Manager, Platform Train Operation
- Assistant Station Manager, Ticket Issuance
- Assistant Station Manager, Ticket Barrier
- Assistant Station Manager, Passenger Guidance

Source: JICA Study Team

Table 5.26: Number of Passengers and Station Size

Station	2030		2040		2050	
	Passengers	Station Size	Passengers	Station Size	Passengers	Station Size
Ngoc Hoi	36,720	B	128,249	A	145,264	A
Phu Ly	11,294	D	19,671	C	25,571	B
Nam Dinh	12,528	D	28,967	B	34,687	B
Ninh Binh	2,715	E	7,310	D	9,565	D
Thanh Hoa	6,351	D	15,763	C	19,625	C
Vinh	11,416	D	27,601	B	32,462	B
Ha Tinh			10,780	D	13,248	D
Vung Ang			4,618	E	5,674	D
Dong Hoi			7,188	D	8,660	D
Dong Ha			6,942	D	8,514	D
Hue			21,409	C	24,835	C
Da Nang			32,910	B	37,260	B
Tam Ky			6,533	D	7,895	D
Quang Ngai			7,197	D	8,631	D
Phu My			4,385	E	5,089	D
Dieu Tri			7,839	D	8,942	D
Tuy Hoa			8,801	D	11,260	D
Nha Trang	16,560	C	27,626	B	33,153	B
Tap Cham	2,884	E	4,185	E	5,354	D
Tuy Phong	6,229	D	8,866	D	10,792	D
Phan Thiet	9,344	D	13,301	D	16,185	C
Long Thanh	15,151	C	27,194	B	37,781	B
Thu Thiem	37,036	B	131,453	A	151,175	A

Source: JICA Study Team

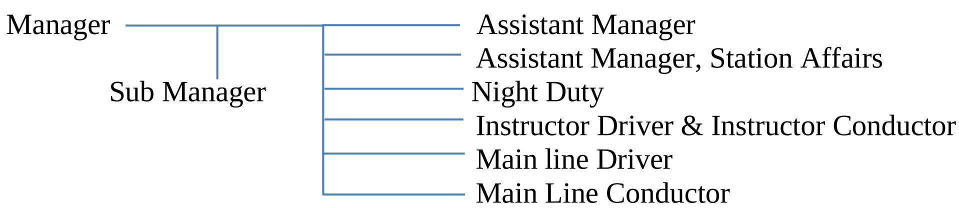
Table 5.27: Number of Employees at each Station

Station		Number of employees		
		2030	2040	2050
Hanoi Branch	Ngoc Hoi	105	197	210
	Phu Ly	58	77	88
	Nam Dinh	62	94	102
	Ninh Binh	29	47	54
	Thanh Hoa	44	69	77
	Vinh	59	91	99
	Ha Tinh		57	63
	Vung Ang		37	41
	Dong Hoi		47	51
	Dong Ha		46	51
	Hue		80	87
	Da Nang		100	106
	Subtotal	357	942	1,029
HCMC Branch	Tam Ky		46	51
	Quang Ngai		49	53
	Phu My		37	40
	Dieu Tri		51	54
	Tuy Hoa		54	60
	Nha Trang	71	94	104
	Tap Cham	30	37	41
	Tuy Phong	43	54	59
	Phan Thiet	53	65	73
	Long Thanh	68	94	111
	Thu Thiem	106	208	222
	Subtotal	371	789	868
Total		728	1,731	1,897

Source: JICA Study Team

(2) Train Driver and Conductor Depot

- Assignment – Driver and Conductor depot.
- A driver and two conductors are assumed to be on duty per 10-car train. With 16-car trains, three conductors are assumed to be on duty.
- An instructor driver is assumed to be assigned per 20 main line drivers, and an instructor conductor is assumed to be assigned per 30 main line conductors.
- Organizational Structure:



Source: JICA Study Team

- Number of Employees – Referring to the Tohoku and Joetsu Shinkansen.

Table 5.28: Number of Employees at the Train Driver/Conductor Depot

Train Driver and Conductor Depot		Number of employees		
		2030	2040	2050
Hanoi Branch	Administrator	6	27	30
	Train Driver	48	241	266
	Train Conductor	77	386	427
	Subtotal	131	654	723
HTMC Branch	Administrator	7	28	31
	Train Driver	57	253	282
	Train Conductor	92	406	452
	Subtotal	156	687	765
Total	Administrator	13	55	61
	Train Driver	105	494	548
	Train Conductor	169	792	879
	Total	287	1,341	1,488

Source: JICA Study Team

(3) Inspection Base

- Assignment – Daily Inspections and regular inspections.
- Maintenance is assumed to be conducted at the base in principle, but the cleaning of rolling stock shall be outsourced.
- Organizational Structure:

Manager
- Base Affairs (General, Account)
- Night Duty
- Engineering Control
- Regular Inspection
- Non-regular Inspection
- Daily Inspection (ATC, et.)
- Station Inspection
- Other Related Companies

Source: JICA Study Team

Table 5.29: Number of Employees at the Inspection Base

Inspection Base	Number of employees		
	2030	2040	2050
Hanoi Branch	38	158	196
HCMC Branch	38	118	156
Total	76	276	352

Source: JICA Study Team

(4) Rolling Stock Workshop

- Assignment – Daily inspections, regular inspections, general inspections, and important parts inspections.
- Maintenance shall be conducted within the workshop, in principle.
- Organizational Structure:

Manager
- General Affairs Section (General, Accounting, etc.)
- Control Section (Process, Spare parts, Equipment)
- Regular/Daily Inspection
- Car Body Group
- Parts Group
- Truck Group
- Station Inspection
- Other Cooperative Companies

Source: JICA Study Team

Table 5.30: Number of Employees at the Rolling Stock Workshop

Rolling Stock Workshop	Number of employees		
	2030	2040	2050
Hanoi Branch	318	1,150	1,252
HCMC Branch	318	1,150	1,252
Total	636	2,300	2,504

Source: JICA Study Team

(5) Equipment/Facilities Depot

- Assignment – Maintenance of tracks, structures and architecture.
- Railway tracks are assumed to be (referring to Table 5.20 Track Structure of HSR):
  - North section (14.0% ballast track, slab track 86.0%),
  - Middle section (32.1% ballast track, slab track 67.9%),
  - South section (37.3% ballast track, slab track 62.7%) and
  - Overall (30.0% ballast track, slab track 70.0%)

- The improved track structures shall be adopted in order to minimize tamping works on the ballast track section. (see Ballast Track of HSR: Table 5.11 Comparison of Ballast Track)
- The equipment/facilities employees shall be dispatched to the Operation Control Center (OCC)
- Equipment/facilities depots at intervals of approximately 40 to 50 km are assumed to be establish.

- Organizational Structure:

Manager
- Sub Manager
- Assistant Manager
- Assistant Manager, Station Affairs
- Engineering Assistant
- Track Inspection Assistant
- Construction Work/Civil Engineering Assistant
- Track Maintenance Work Assistant
- Machine/Track Maintenance Assistant

Source: JICA Study Team

- Number of employees – Estimated with reference to the cases of the Tokaido and Sanyo Shinkansen and reflecting improvements of the ballast track maintenance.

- It is assumed that the necessary manpower for ballast track sections are 1.95 persons per kilometer and 1.45 persons per kilometer for slab track sections.
- Since the number of train sets is assumed to increase drastically in 2040 after the opening of the entire line, the number of employees are also assumed to increase by 10% from 2030 levels.

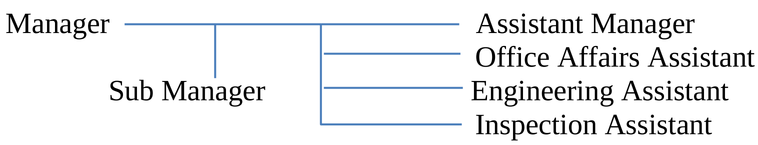
Table 5.31: Number of Employees at the Equipment/Facilities Depot

Equipment/Facilities Depot	Number of employees		
	2030	2040	2050
Hanoi Branch	429	1,299	1,299
HCMC Branch	595	1,411	1,411
Total	1,024	2,710	2,710

Source: JICA Study Team

(6) Power Supply Depot

- Assignment – Maintenance of power supply equipment/facilities.
- Maintenance within the depot is mostly assumed, except some equipment/facilities such as the visual inspection of overhead contact line and cleaning of insulators shall be outsourced.
- The power supply employees shall be dispatched to the Operation Control Center (OCC).
- The power supply depots shall be located in approximately 50 km intervals.
- Organizational Structure:



Source: JICA Study Team

- Number of employees – 1.0/km is assumed as the number of employees per kilometer, with reference to the number of employees at the start of operation of the Tokaido Shinkansen. However, in the case of Vietnam, since it is the first time to operate a train with electrification, a 20% increase in the assumption of number of employees is considered.

Table 5.32: Number of Employees at the Power Supply Depot

Power Supply Depot	Number of employees		
	2030	2040	2050
Hanoi Branch	337	990	990
HCMC Branch	435	1,046	1,046
Total	772	2,036	2,036

Source: JICA Study Team

(7) Signaling/Telecommunications Depot

- Assignment – Maintenance of signal, telecommunication and information systems.
- Maintenance shall be mainly conducted within the depot, except the replacement of electric point machines, etc., which shall be outsourced.
- The signaling/telecommunications employee shall be dispatched to the Operation Control Center (OCC).
- A base station shall be placed at each of the north and south sections, with branch stations placed at approximately 50 km intervals.

- Organizational Structure:

[Depot Head Office]

- Manager
  - Sub Manager
  - Assistant Manager
  - Office Affairs Assistant
  - Engineering Assistant

[Branch Office]

- Branch Office Manager
  - Branch Office Sub-Manager
  - Assistant Branch Office Manager
  - Office Affairs Assistant
  - Inspection Assistance

Source: JICA Study Team

- Number of employees – 1.0/km is assumed as the number of employees per kilometer, with reference to the number of employees at the start of operation of the Tokaido Shinkansen.

Table 5.33: Number of Employees at the Signaling/Telecommunications Depot

Signal/Telecommunication Depot	Number of employees		
	2030	2040	2050
Hanoi Branch	284	750	750
HCMC Branch	362	792	792
Total	646	1,542	1,542

Source: JICA Study Team

(8) Material Center

- Assignment – Requisition, receipts and payment, storage, inspection, delivery, procurement, repair and transport contracts for the goods required at the Vietnamese HSR field offices.
- Organizational Structure:

- Manager
  - Sub-Manager
  - Accounting Group (Budget, Payment, Settlement and Financial control)
  - Material Group (Requisition, Receipt/Payment, Storage, Inspection, Distribution, Repair, and Transport Contract of Goods)
  - Contract Examiner

Source: JICA Study Team

Table 5.34: Number of Employees at the Material Center

Material Center	Number of employees		
	2030	2040	2050
Hanoi Branch	50	100	100
HCMC Branch	50	95	95
Total	100	195	195

Source: JICA Study Team

5.3.5 Operation and Management Organization for Five-step Case

Similarly, for Five-step Case, the number of train sets (which is a precondition for considering the railway organization) are shown in Table 5.35. For the railway structure and track structure, the same preconditions as Two-step Case are applied as shown in Table 5.19 and Table 5.20.

Table 5.35: Number of Train Sets for Five-step Case

Section	2030	2040	2050	2060	2070	Remarks
Hanoi – Vinh		**46	**60	**68	***106	Train operation time from 6:00 to 24:00
Vinh – Da Nang					***106	
Da Nang – Nha Trang				**34	***106	
Nha Trang – Thu Thiem			**50	**82	***106	
Long Thang – Thu Thiem	*20	*28				

Note: * 5-car trains, ** 10-car trains, *** 16-car trains
Source: JICA Study Team

Basically, the number of employees for Five-step Case is calculated under the same conditions and assumptions described for Two-step Case. However, the following points are considered for the opening of the HSR between Long Thang and Thu Thiem (36.0 km) in 2030.

- The head office and branch offices should be as simplified as possible.
- The field offices shall secure the staff necessary for collective work, in consideration of future skills training.

The number of employees for each type of office is shown in Table 5.36. For comparison, the number of employees from Two-step Case is shown in Table 5.37.

Table 5.36: Number of Employees at Each Office for Five-step Case

	2030	2040	2050	2060	2070
Head Office	20	90	173	173	173
Branch Offices	30	224	388	388	388
Field Offices	330	2,350	5,005	8,123	13,550
Total	380	2,664	5,566	8,684	14,111
Station	112	484	940	1,354	1,985
Driver/Conductor-depot	13	185	432	763	1,911
Rolling Stock Inspection Base	32	70	208	334	725
Rolling Stock Workshop	73	391	880	1,284	2,446
Track Maintenance-depot	40	469	1,024	1,783	2,710
Power Supply Station-depot	30	382	775	1,342	2,036
Signaling/Telecommunications-depot	25	319	646	1,118	1,542
Material Center	5	50	100	145	195
Total	330	2,350	5,005	8,123	13,550

Source: JICA Study Team

Table 5.37: Number of Employees at Each Office for Two-step Case

	2030	2040	2050
Head Office	173	173	173
Branch Offices	388	388	388
Field Offices	4,269	12,131	12,724
Total	4,830	12,692	13,285
Station	728	1,731	1,897
Driver/Conductor-depot	287	1,341	1,488
Rolling Stock Inspection Base	76	276	352
Rolling Stock Workshop	636	2,300	2,504
Track Maintenance-depot	1,024	2,710	2,710
Power Supply Station-depot	772	2,036	2,036
Signaling/Telecommunications-depot	646	1,542	1,542
Material Center	100	195	195
Total	4,269	12,131	12,724

Source: JICA Study Team

5.4 Estimated Operation and Maintenance Cost

This section has been removed because of confidential information.

6. Social Infrastructure

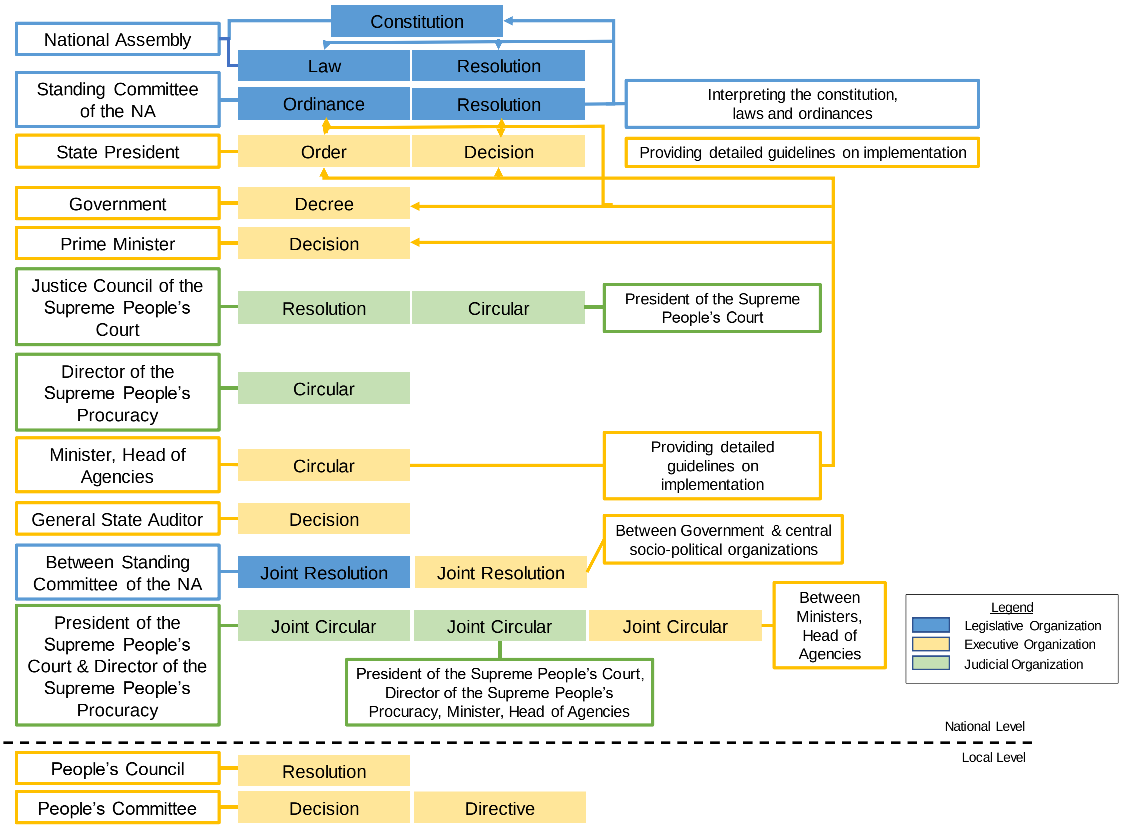
6.1 Laws and Regulations

6.1.1 Legal Framework for Railway Construction in Vietnam

(1) Overview

The governing system in Vietnam is shown in below table. It is made from four levels of governance, which are: National, Provincial, District and Commune. The National Assembly is the highest state authority, with the Standing Committee the permanent body of the National Assembly which issues decrees, provide oversight of the People's Councils and other committees, to serve as the constitutional/legal monitor of the Government. The Government is the highest executive institution that implement the intention of the National Assembly, composed by the Prime Minister and other Ministers. The People's Councils are the local organization, which members are elected by local residents and pass resolutions to implement higher-level measures and direct local affairs. People's Committees are the local administrative state bodies responsible for the implementation of the constitution, laws and resolutions.

The main legal system of Vietnam is the system of the law (Law) prescribed by the National Assembly, the Decree by the government, and the Circular ordinance prescribed by the ministries and agencies.



Source: Key Features of Vietnam's Legal System, July 2013, Cambridge

Figure 6.1: Overview of the Legal System in Vietnam

(2) Railway Legislations

Like many countries, laws and regulations related to the railway sector is diverse. This section will focus on the main legislations, including the Railway Law (Law 03/2017/L-CTN) which has been enacted for the railway business management and operation and the Law on Construction (50/2014/QH13) which has been enacted for the construction and management of infrastructure, including railways.

1) Railway Law and Related Legislations

- Railway Law

In June 2017, the updated Railway Law (Law 03/2017/L-CTN) was passed by the National Assembly, stipulating railway infrastructure planning, investment, construction, protection, maintenance and development, as well as railway industries and businesses. The new Railway Law is structured as per below table. Compared to the Railway Law enacted in 2005, new provisions have been added, including Chapter 8 on high-speed railways.

Table 6.1: New Railway Law (Law 03/2017/L-CTN)

Chapter 1	General Provisions
Chapter 2	Railway Infrastructure
Chapter 3	Development of Railway Industry, Means/Forms of Railway Transportation
Chapter 4	Railway Staff Providing Direct Train Services
Chapter 5	Railway Traffic Rules and Signals Ensuring Railway Traffic Order and Safety
Chapter 6	Railway Business
Chapter 7	Urban Railway
Chapter 8	High Speed Railway
Chapter 9	State Management of Railway Operations
Chapter 10	Implementation Provisions

Source: JICA Study Team, based on the Vietnamese Railway Law, 2017

In Chapter 1 Article 3, the high-speed railway is defined as **"a type of national railways with a designed speed from 200 km/hour and more, a gauge width of 1,435 mm, double track, and electrified railways"**. According to Chapter 8 on the high-speed railway, such infrastructure shall efficiently connect large urban areas, economic centers, key economic regions and other transport modes. It also states that the State will play the leading role in the construction, investment, management, maintenance, and operation of the high-speed railways and the land for construction shall be approved by competent government agencies according to the construction master plan. In regards to the high-speed rail infrastructure, it stipulates that it shall be stable and sustainable and shall meet the technical requirements on safety, environment, fire and explosion prevention corresponding to the invested high-speed rail. The law also stipulates that the power supply system shall be centrally and stably controlled and monitored, and shall be capable of preventing interruption of train operation.

Chapter 8 consist of Articles shown in below table.

Table 6.2: Chapter 8 - High-Speed Railways

Article 78	General Requirements for High-Speed Railway
Article 79	Policies for Developing High-Speed Railway
Article 80	Requirements for High-Speed Railway Infrastructure
Article 81	Management, Exploitation, and Maintenance of High-Speed Railway
Article 82	Safety Management of High-Speed Railway

Source: JICA Study Team, based on the Vietnamese Railway Law, 2017

Other updates in the Railway Laws other than the high-speed railway include clauses that stipulate the State to prioritize and concentrate resources on investment in the development, upgrading, maintenance and protection of the national and urban railway infrastructure facilities. Priority will be given to the development of national railway infrastructure under planning through the allocation of central budget funds. The law also stipulates investment incentives such as allocation of land areas without land use levy for national railway, concessional loans from the State's investment credit source or government-guaranteed loans, preferential corporate income tax rates, etc. will be provided to the railway infrastructure business, railway transport business, urban railway business, and railway industry. Furthermore, railway infrastructure businesses will be given exclusive radio frequencies in service of railway transport administration and access to the traction power supply system in service of train operations.

- Enforcement of the Railway Law

As a supplement to the Railway Law, a Decree on the Detailed Stipulation and Guide to the Implementation of Several Articles in the Railway Law (Decree 14/2015/ND-CP) has been adopted to stipulate detailed provisions for actual implementation of the Railway Law. With the new law including the high-speed railway, it is deemed to be necessary for the adaptation for a new Decree focused on high-speed railways.

Table 6.3: Decree on Specifically Stipulating and Guiding the Implementation of Several Articles in the Railway Law (Decree 14/2015/ND-CP)

Chapter 1	General Provisions
Chapter 2	Railway Infrastructure
Chapter 3	Railway Business
Chapter 4	Railway Vehicles
Chapter 5	List of Dangerous Goods and Transport of Dangerous Goods on Railways
Chapter 6	Urban Railway
Chapter 7	Responsibilities of Ministries, Branches, and Provincial-Level People's Committees to Ensure Railway Communication and Transport Order and Safety
Chapter 8	Implementation Provisions

Source: JICA Study Team, based on the Decree on Specifically Stipulating and Guiding the Implementation of Several Articles in the Railway Law, 2015

2) Law on Construction

The Law on Construction (Law 50/2014/QH13) is the law that stipulates the planning, designing, construction and management of civil structures and facilities, including railways. The Ministry of Construction is the main ministry for authorization, but for the railway (national railways and urban railways), the authority has been delegated to the Ministry of Transport and its related organizations. Further, since construction activities stipulated in this law include maintenance, the maintenance of facilities constructed under the law will also be subject to the law. Below table show the provisions in the Law on Construction.

Table 6.4: Law on Construction (Law 50/2014/QH13)

Chapter 1	General Provisions
Chapter 2	Construction Planning
Chapter 3	Construction Investment Projects
Chapter 4	Construction Survey and Design
Chapter 5	Construction Permits
Chapter 6	Construction Works
Chapter 7	Construction Investment and Construction Contracts
Chapter 8	Conditions of Construction Operation Capability
Chapter 9	Management Responsibility on Construction Investment Activities of State Agencies
Chapter 10	Implementation Provisions

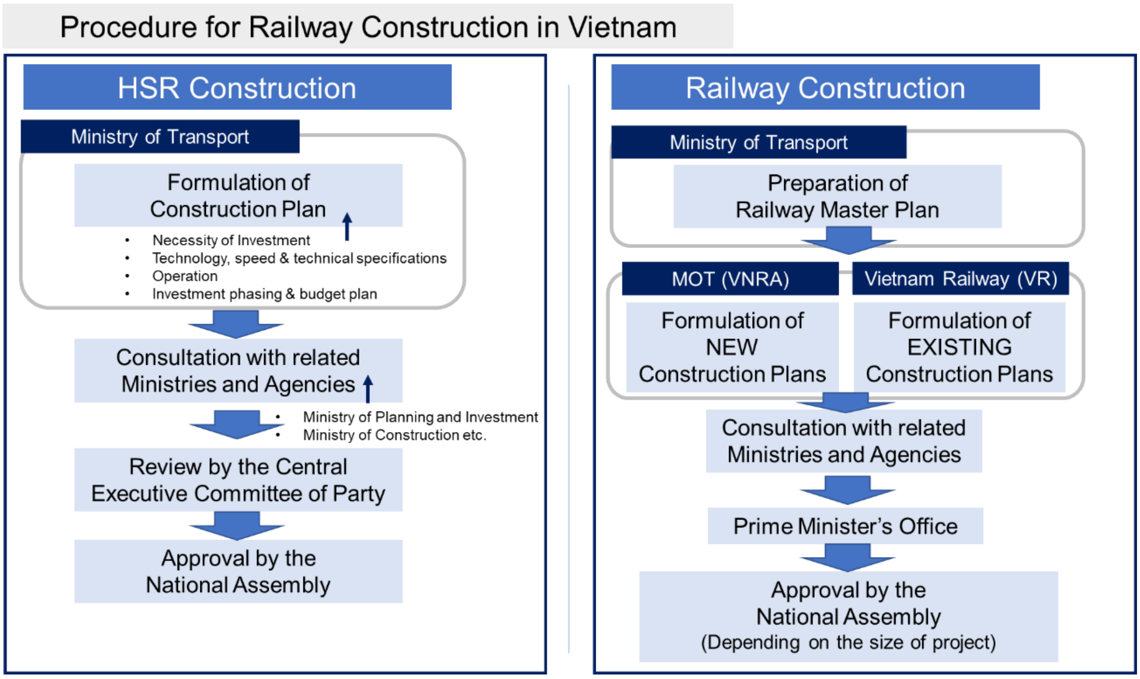
Source: JICA Study Team, based on the Vietnamese Law on Construction, 2014

(3) Procedure for Railway Construction and Land Acquisition

1) Procedures for Railway Construction

Various Ministries and agencies play a role during the planning phase of railway construction. The Ministry of Transport (MOT) is responsible in formulating medium to long-term transport strategies and formulation of the railway master plan. The Ministry of Planning and Investment is responsible in drawing up a conceptual plan on social and economic development strategy, with coordination with other Ministries. The Ministry of Construction is responsible in formulating a master plan on national city planning and is in charge of the parts of the project under government control. The People's Committee of the cities formulates the comprehensive plan and implements the city planning schemes.

MOT is in charge of implementing the plans of railway construction work. In principle, construction of a new railway is assigned to the Vietnam Railway Administration (VNRA), a bureau within MOT, and remodeling of existing railways is assigned to Vietnam Railways Corporation (VNR). Projects such as the High-Speed Railway Project, with a total investment cost over VND 10,000 billion (approximately USD 430 million), would fall under the category of National Important Projects based on the Public Investment Law, and would, therefore, require Governmental approval and submission to the National Assembly.



Source: JICA Study Team, based on interviews with the Local Consultant

Figure 6.2: Procedure for Railway Construction in Vietnam

2) Land Acquisition

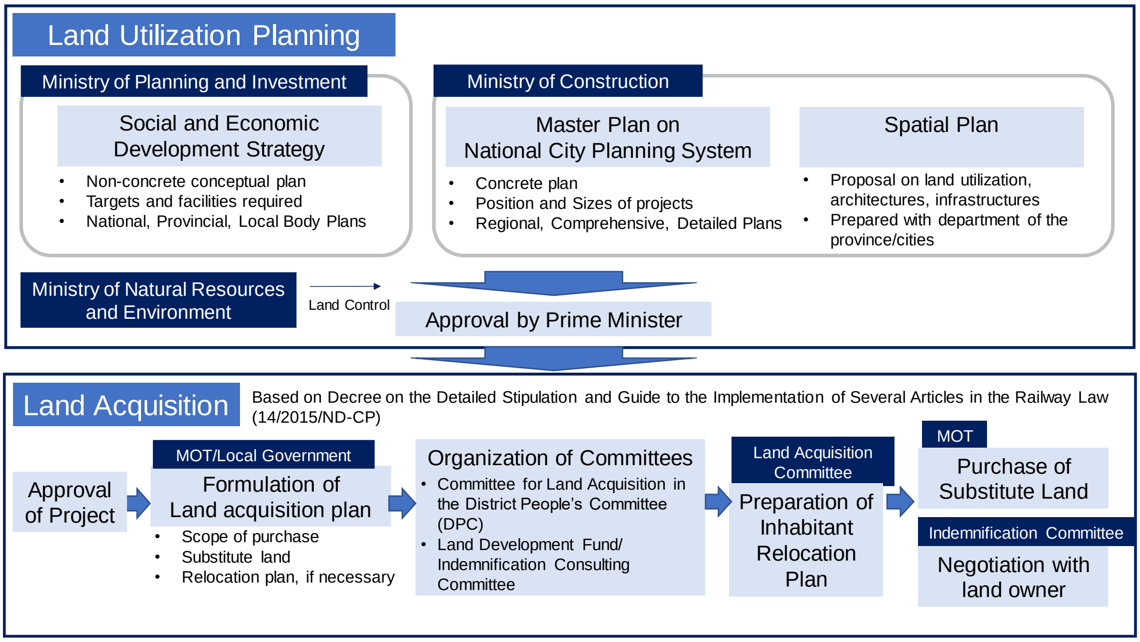
The principal legislation relevant for land acquisition for railway projects is the Law on Land (Law 45/2013/QH13), which was amended from the previous Land Law of 2003[1] as well as the Railway Law. The Land Law stipulates the legal framework for land acquisition, compensation,

[1] The major changes from the 2003 Land Law includes the abolishment of differences between local and foreign investors for land acquisition. With the new Law, local and foreign investors both may acquire land through land allocation (for now, it is limited to residential land) or lease the land.

assistance and resettlement. The related Decrees provides additional guidelines on land use, compensation, assistance and resettlement.

After the project has been approved, a Land Acquisition Committee is organized in the District People's Committee and the land acquisition plan is formulated to start the negotiations with the land owners.

In the past, there seem to have been issues where the land price of lands that were remained unsold in areas adjacent to newly constructed roads skyrocketed after the construction work compared with the cost at which lands were sold to constructors, causing complaints on unfairness. Similar problems were experienced in Japan in the past, and land readjustment schemes were developed. The details on the experiences in Japan will be explained within the next section.



Source: JICA Study Team, based on the Vietnamese Law on Land

Figure 6.3: Land Utilization Planning and Land Acquisition

(4) Legal Framework of PPP

Public-Private Partnership projects, where the public sector and private sector conduct infrastructure development in cooperation, were governed by Decree 108/2009/ND-CP and Decision 71/2010/QD-TTg by the Prime Minister. In 2015, however, the Decree on Public-Private Partnership Investment (Decree 15/2015/ND-CP) was enacted, unifying the Decree and Decision. In May 2018, the Government has issued a Decree on Investment in the form of Public Private Partnerships (Decree 63/2018/ND-CP), replacing Decree 15. As of July 2018, Decree 63 is the latest legislation on PPP projects.

The PPP models mentioned in Decree 63 include:
Project contract; Build-Operate-Transfer contracts (BOT); Build-Transfer-Operate contracts (BTO); Build-Transfer contracts (BT); Build-Own-Operate Contracts (BOO); Build-Transfer-Lease Service Contacts (BTL); Build – Lease Service – Transfer Contracts (BLT); Operate – Management Contract (O&M) and Mixed Contract.

Under Decree 63, procedures were simplified, where investors no longer are required to obtain an investment registration certificate unlike in the past. On the other hand, the new Decree has increased the minimum equity requirement for private investors from 15% to 20%, for projects with a total investment capital of up to VND 1,500 billion. It should also be noted that even with Decree 63, the mechanism of risk-sharing between the government and the private sector (including income guarantee and exchange conversion) is not clearly defined, thus, investment hurdles remain high. Furthermore, although Decree 63 stipulates that the relevant contracts of the project may apply to foreign law, it does not specify whether foreign law can be applied to contracts where one of the signatories is a foreign legal entity. Also, Decree 63 allows investors and project enterprises to mortgage land use rights and assets attached to land and the right to trade in project's equipment. However, the Law on Land and the Civil Law do not stipulate clearly whether or not foreign bank branches in Vietnam are allowed to mortgage land use rights and assets attached to land. Moreover, the Decree does not specify the evaluation methodology for unsolicited proposals. Therefore, clarification, as well as coordination with other laws, are still required. Currently, the Ministry of Planning and Investment is considering the submission of a new PPP law to the National Assembly in 2020/2021.

Implementation of PPP projects, including the transport sector, basically follows the below procedure (however, the approval and implementation procedure would vary depending on the project size and sectors):

1) Evaluation of the pre-feasibility study and decision on the project. Once the decision is made, it is announced publicly
2) Appraisal and approval of the feasibility study
3) Decision on the government subsidies and investment guarantee scheme
4) Selection of investors
5) Negotiation and signing of contract
6) Implementation of project, settlement and transfer of works.

For the High-Speed Railway Project, it is likely it will be categorized as a National Important Project, based on the Public Investment Law Article 7. Decree 63 stipulates National Projects as follows:

- National Assembly decides the investment policy for national projects
- The State Appraisal Council evaluates the F/S of national projects.
- Prime Minister approves F/S of national projects

6.1.2 Legal Framework for Shinkansen Construction in Japan

(1) High-Speed Railway Legislation

In Japan, the high-speed railway is mainly regulated by the following laws and regulations:

- Nationwide Shinkansen Railway Development Act (No. 71, 1970)
- Railway Business Act (No. 92, 1986)
- Railway Operation Act (No. 65, 1900)
- Ordinance for Enforcement of the Nationwide Shinkansen Railway Development Act (No. 86,1970)
- Order for Enforcement of the Nationwide Shinkansen Railway Development Act (No. 272, 1970)

The Nationwide Shinkansen Railway Development Act has been enacted for the development of high-speed railway network across the nation, for the contribution of the development of the national economy, expansion of the living sphere of the citizens, and regional development. Below table shows the provisions and articles of the Act:

Table 6.5: Nationwide Shinkansen Railway Development Act (No. 71, 1970)

	Clauses	Articles
1	General Provisions	1. Purpose
		2. Definitions
		3. Shinkansen Railway Routes
2	Shinkansen Railway Constructions	4. Basic Plan
		5. Instruction to Research on the Construction Line
		6. Designation of Operator and Constructor
		7. Development Plan
		8. Instruction to Construct the Construction Line
		9. Construction Implementation Plan
		10. Designation and Cancellation of Conduct Restriction Area
		11. Restriction of Conduct
		12. Entry and Temporary Use of Land Occupied by Other Persons
		13. Responsibility of Construction Costs
		14. Special Provisions on Application of the Railway Business Act
3	Major Improvement Works of Shinkansen Railways	15. Designation of Owner Operator
		16. Allowance Reserve Plan
		17. Reserve of Allowance for the Major Improvement Works of Shinkansen Railways
		18. Authorization of Implementation Plan for Major Improvement Work
		19. Revision to Implementation Plan for Major Improvement Work
		20. Application of the Provision on Entry and Temporary Use of Land Occupied by other Persons
		21. Special Provisions on Application of the Railway Business Act
		22. Revocation of Authorization of Implementation Plan for Major Improvement Work
		23. Transfer Etc. of Railway Business
4	Miscellaneous	24. Mandate to the Ordinance of MLIT
5	Penal Provisions	25 to 27 Penalties

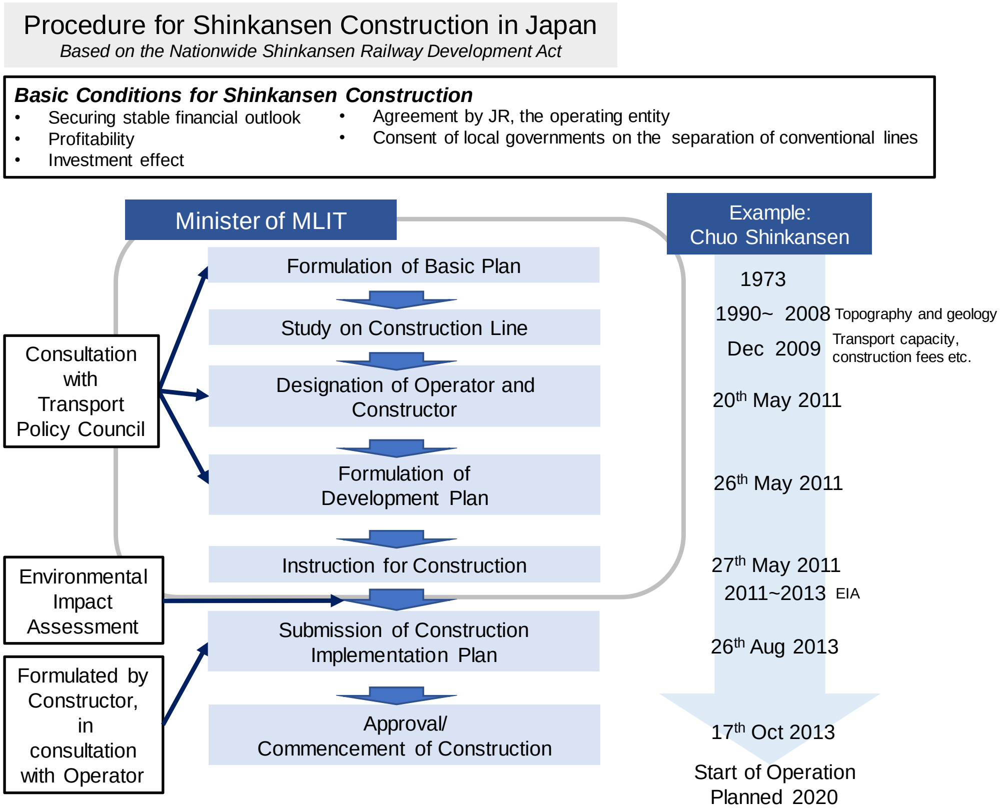
Source: JICA Study Team, based on Japan's Nationwide Shinkansen Railway Development Act, 1970

(2) Procedure for Shinkansen Construction

Below figure shows the procedure for the Shinkansen construction in Japan, based on the Nationwide Shinkansen Railway Development Act (No. 79, 1970). After the basic plan is formulated, the Minister of the Ministry of Land, Infrastructure, Transportation and Tourism instructs surveys to be conducted, including topographical and geological surveys, transport capacity, construction fee, technologies for facilities and rolling stock, etc. Next, the Minister designates the operator and constructor and formulates the Development Plan, in consultation with the Transport Policy Council[2] and other councils[3]. Once the Development Plan is formulated, the Minister will instruct the Constructor for construction, and the constructor will prepare the implementation plan in consultation with the operator. Finally, once the implementation plan is approved, construction will be started.

[2] Transport Policy Council is a council established based on the Ministry of Land, Infrastructure, and Transport Establishment Act (No. 100, 1999), investigating and deliberating important issues in regards to the transport policy, providing opinions to the concerned Minister. The Transport Policy Council has 8 branch councils; transport system, technology, tourism, land transport, maritime affairs, port, aviation, and weather.

[3] Land Council is consulted on the use, development and maintenance of land. Social Infrastructure Council is consulted on matters concerning real estate businesses, lands for housing, architecture, and public facilities.



JR= Japan Railways
Source: JICA Study Team, based on Japan's Nationwide Shinkansen Railway Development Act

Figure 6.4: Procedure for Shinkansen Construction

(3) Land Acquisition

The laws related to land control and acquisition in Japan is shown in the table below. The land acquisition procedure for the construction of Shinkansen begins after the construction route is determined and if it includes restricted areas, plans are prepared so that the conditions of land are not changed. Furthermore, in Japan, the development of station squares and side roads of railway lines are required to be carried out according to the plans of the cities funded by the local government. Therefore, the development plans need to be discussed at the City Plan Council.

Table 6.6: Regulations on Land Control

1	National Spatial Planning Act	No. 205, 1950
2	National Land Use Planning Act	No. 92, 1974
3	City Planning Act	No. 100, 1968
4	Building Standard Act	No. 201, 1950
5	Land Expropriation Act	No. 219, 1951
6	Land Readjustment Act	No. 119, 1954
7	Urban Redevelopment Act	No. 38, 1969
8	Promotion of integrated land development in metropolitan areas and railway line special measures act	No. 61, 1989

Source: JICA Study Team

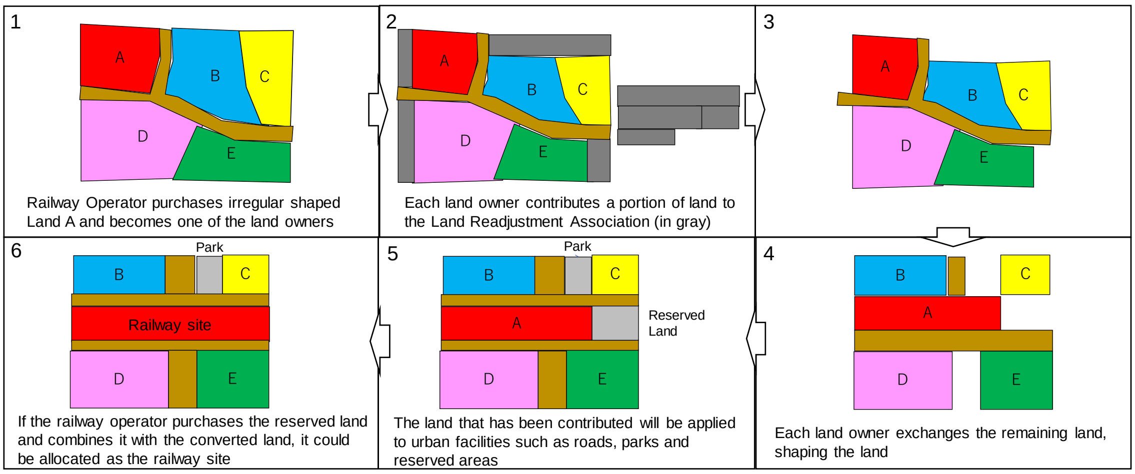
Land acquisition of public-work sites is usually conducted through negotiations between the project owner and the land owner, but in cases where an agreement cannot be reached, a forced expropriation is conducted based on the Land Expropriation law. It should also be noted that the compensation land price is based on the date of the notification of authorization of project and is not affected by the increased prices after the project commencement.

In Japan, there is an Act called the Land Readjustment Act (No. 119, 1954) that is utilized for constructions of public facilities. According to this Act, land readjustment projects changing the land character and establishing or changing public facilities may be conducted for land within the urban planning area to improve the construction of public facilities and to promote the usage of residential land.

An example for land readjustment is shown in below figure. The readjustment follows below procedures:

- Railway Operator purchases an irregular shaped land and becomes one of the land owners
- Each land owner contributes a portion of land to the Land Readjustment Association
- Each land owner exchanges the remaining land, reshaping the land
- The land that has been contributed will be applied to urban facilities such as roads, parks and reserved areas
- If the railway operator purchases the reserved land and combines it with the converted land, it could be allocated as the railway site

With this readjustment, the land area will be smaller than what was originally owned. However, with the reshaping of the land and with roads and facilities constructed, the asset value per area increases, thus the asset value of the entire site is expected to increase.



Source: Survey on Myanmar Railway New Line Construction (MLIT, 2016)

Figure 6.5: Example of Railway Land Readjustment

(4) Safety Measures

In Vietnam, the New Railway Law includes the safety provisions in Chapter 5 "Railway Traffic Rules and Signals Ensuring Railway Traffic Order and Safety." For the high-speed railway, Article 82 stipulates the "Safety Management of High-Speed Railway," though it only stipulates that:

- Newly built or upgraded high-speed rail shall be evaluated and certified for system safety before being put into operation
- Operators operating high-speed rail activities shall build and maintain a safety management system

For construction works, the Decree on Quality Management and maintenance of Construction Works (46/2015/ND-CP) has been stipulated including safety provisions, which also apply to foreign contractors.

For ODA projects financed by the Government of Japan, "The Guidance for the Management of Safety for Construction Works in Japanese ODA Project" is applied. This guideline has been created in order to prevent occupational accidents and public disasters in construction projects of public facilities etc. by ODA. The guidance compiles basic policy on safety management and technical guidelines on safety construction etc. The basic policy for safety management described in the guidance are:

- Thorough removal of cause
- Thorough preventive measures
- Thorough compliance with relevant laws and regulations to which JICA project is applied
- Thorough prevention of public disaster
- Thorough implementation of PDCA cycle[4] for safety management
- Thorough information sharing with members of the project
- Thorough participation in construction work safety measures for all stakeholders

The guideline is created with six Chapters, including formulation of safety plans, identification of responsibilities of each stakeholder, execution of safe works, measures for prevention, etc. Below table shows the list of Chapters in the guidance.

Table 6.7: The Guidance for the Management of Safety for Construction Works in Japanese ODA Project

Chapter 1	General Rules
Chapter 2	Basic Policies for Safety Management
Chapter 3	Contents of the "Safety Plan"
Chapter 4	Contents of the "Method Statements on Safety"
Chapter 5	Technical Guidance for Safe Execution (by the Type of Work)
Chapter 6	Technical Guidance for Safe Execution (by the Type of Accident)

Source: JICA Study Team, based on the Decree on Quality Management and maintenance of Construction Works (JICA, 2014)

6.1.3 Efforts and Procedures Required for Introduction of HSR from Legal Standpoint

High-speed railway is a completely different system from conventional lines. Therefore, the establishment of an independent legal basis for the design, construction and operation of the high-speed railway is important in the introduction of such railway. In Vietnam, the first step was taken through the addition of the chapter on high-speed railways in the Railway Law. However, it still lacks the specific details and procedures of actual implementation. In Japan, the enforcement procedures have been stipulated through the National Shinkansen Railway Development Act, including the formulation of basic plans, maintenance plans, and construction implementation plans, as well as provisions on the allowance plan, and the decision of construction is to be made by the Minister of the Ministry of Land, Infrastructure, Transport and Tourism. Furthermore, smooth acquisition of land is a universal issue when conducting public works, including high-speed railways. As a measure for this, Japan adopted a land readjustment method in which landowners provide land to create public land. These methods could also be considered in Vietnam.

[4] PDCA= Plan, Do, Check, Act

The legal system recommended for HSR is as per below, summarized in the figure following the explanations:

1) Government of Vietnam

- Law: High-speed railway has been defined in the Railway Law
- Decree: As supplement to the Railway Law, Decree for the procedures for actual implementation and operation is recommended to be formulated. The Nationwide Shinkansen Network Construction Law in Japan can be referred.
- Circular: It is recommended to stipulate MOT's control on safety, inspection and certification of the new line, certification of new rolling stock, certification of driver license for high-speed railways. It shall also include technical specifications announced to the railway organization and act as a performance standard that would enforce the introduction of new technology.

2) Railway Organization

As mentioned in Chapter 5 of this report, it is necessary for the Vietnamese Government to formulate an institutional system (regulator, executing agency, HSR operator) for the implementation of the high-speed railway. In the organizational level, standards and manuals need to be formulated as follows:

- Standards: It is recommended to include technical standards for construction, operation and maintenance. It is assumed to be prepared by the Railway Organization according to the Railway Law and regulations mentioned above. It shall be submitted to MOT for approval.
- Manuals: It is recommended to include the specific procedures for construction, operation and maintenance. It is assumed to be prepared by the Railway Organization according to the regulations and internal standards.

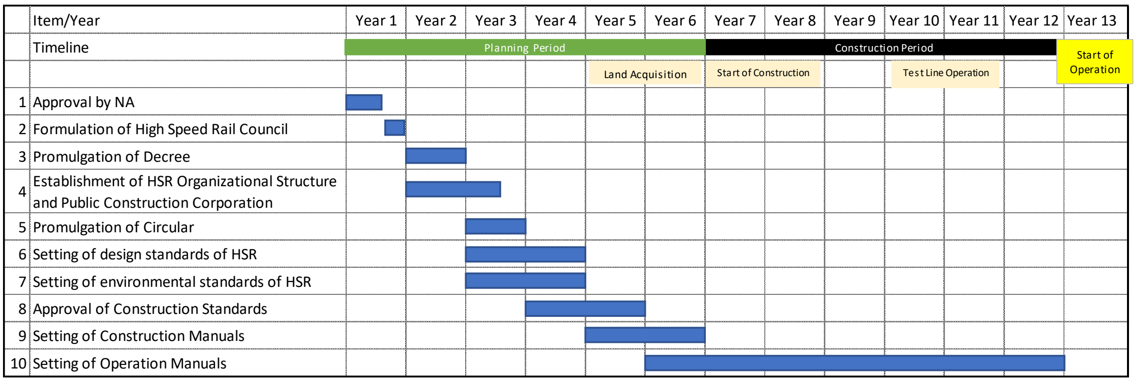
Enactor	Classification	Contents	Current Condition
Government of Vietnam/ Ministry of Transport (Regulator)	Railway Law	• Definition, policies, requirements	• Amendments to the Railway Law, including the definition of High-Speed Railway has been stipulated
	Decree	• Organizational and Financial Structure • Construction Procedures	• Details are not developed
	Circular	• Safety procedures • Certifications (new line, rolling stock, drivers) • Technical Specifications	• Details are not developed
Railway Organization (Constructor and Operator)	Standards	• Standards for Construction, Operation and Maintenance of HSR	• Details are not developed
	Manuals	• Manuals for Construction, Operation and Maintenance of HSR	• Details are not developed

Source: JICA Study Team, based on the Vietnamese Railway Law

Figure 6.6: Structure of Legal System and Technical Standards of HSR

The expected necessary period for the preparation of the legal system and technical standards to is shown in below table.

Table 6.8: Sample Timeline for Legal System and Technical Standards



Source: JICA Study Team

3) Recommendations on the Legal System

The opening of the railway brings tremendous benefits to residents and local governments. In Japan, the "Railway Construction Act" for the entire railway network was enacted in 1892, considering the importance of railway networks. It was stipulated that the railway network is to be built under the responsibility of the government and by the funds of the country. The revised "Railway Construction Act" was issued in 1922, when the Japanese main railway network reached completion. For the local network, its construction route was decided at the National Diet, under the understanding that the local network shall be built and operated by the responsibility of the state. However, due to the progress of motorization, the profitability of local lines became poor. On the other hand, construction of railway was a proposition for local elected members of the National Diet, and together with the management deficit of the JNR, it became a topic of political dispute. Because of this contradiction, the "Railway Construction Act" was abolished along with the reform of the National Railways in 1987.

While the general plan is formulated under the Nationwide Shinkansen Railway Development Act, the actual construction decisions are left to the Minister of Land, Infrastructure, Transport and Tourism. Although it is necessary to confirm priorities and consult prospects for securing financial resources etc. with councils, railway business operators, and local governments, it seems that pressure from the National Diet has been relaxed over the years.

Vietnam's construction of the high-speed railway is expected to receive various opinions from numerous stakeholders as it will have a great influence on regional development. In order to obtain consensus as a country, discussions shall be held at various stages and in order to avoid confusions, clear division of roles is indispensable among the National Assembly, government agencies, regional People's Council and People's Committee.

6.2 Development of the Railway Industry and Supporting Sectors

6.2.1 Background

Introduced by the French during the colonial period and operational for more than 100 years, Vietnam's railway systems is one of the oldest and most complete in the region. Despite early progress, however, hampered by repeated wars and political upheavals, the Vietnamese railway has suffered from insufficient maintenance and upgrading over the years and is now largely outdated. Consequently, contrary to the robust growth of the road and air travel sectors, Vietnam's railway industry has been losing market share, slipping into a reputation as a less attractive option for individual passengers and logistics companies alike.

On a global scale, it is recognized that well-planned investments in rail infrastructure can stimulate local economies. As urbanization continues, urban rail network is ever in demand. Appropriately designed long-distance trains improve mobility for people and goods. New rail stations can spur regional development. Strategic investment in railroad infrastructure can contribute to the nation's long-term economic growth by creating new jobs, improving logistics and expanding export industry. Simultaneously, strategic investment in the training of skilled human resources can build competitive and sustainable supporting industries around the railway industry.

6.2.2 Advantages of the Railway Technology

(1) Multidisciplinary and Advanced Skills and Technologies

Operating and maintaining the railway requires multiple fields of engineering knowledge, including civil, electrical, mechanical, etc. It is an integrated system involving rolling stock, structures, power supply, signaling and telecom systems, etc. Not only are diverse skills and technologies needed, but each is required at a relatively high level, which means that establishing the railway industry is equivalent to enhancing the country's overall level of technical quality.

It is possible to operate and sustain the railway without appropriate technologies and supporting sectors in the country. In fact, globally that is the case in most countries, including for example India and Thailand. However, if unable to supply needed parts and services domestically, the country has no choice but to continue to rely on imports, which could mean higher input cost, slower delivery time, and lower security/stability.

(2) Technology Adaptable to Other Industries

Another point to note is that many of the skills required for the railway industry are versatile and adaptable to other industries, such as manufacturing and maintenance of motorbikes and automobiles. Though mainly in assembly rather than in manufacturing, Vietnam already has a strong motorcycle industry. Vietnam's mechanical supporting industry may still be developing, but it shows great potentials with a strong capacity to absorb and incorporate new technologies. Vietnam also has a large market for motorcycle and automotive vehicles and a growing domestic and regional market for the railway. Japan has been one of the top investors in Vietnam, and it is no secret that since early 2000s Japan has strategized Vietnam as their future manufacturing hub.

6.2.3 Development and Opportunities in Southeast Asia

(1) Railway Development in Vietnam

The Government of Vietnam has recognized the need to step up investment in upgrading the existing railway system; its agenda includes:

- construction of new railway lines linking to seaports[5];
- trans-Asian railways connecting neighboring countries[6];
- urban railways in Hanoi and Ho Chi Minh City[7]; and
- high speed rail (HSR) on the north-south axis[8].

[5] Master Plan of Viet Nam Seaport System to 2020
[6] Trans-Asian Railway Project
[7] Adjustment to the Master Plan for Viet Nam Railway Transport Development, 2009
[8] North – South Express Railway Plan

A rapid transit network for Ho Chi Minh City was proposed in 2001, and its first line is currently under construction. The long-term plan envisages ultimately developing a comprehensive system comprised of several underground metro routes and possibly light rail lines and even monorails. An overall transport development plan for Hanoi including a rapid transit system was approved in July 2008. As of 2018 two of the Hanoi metro lines are under construction. On national scale, the north-south HSR, currently being considered by the Ministry of Transportation, is envisaged to link big cities and economic zones in the near future.

Under Vietnam's Railway Development Strategy 2020, the Government has announced its aim to increase the share of passenger and freight transport by railway from 0.5% of the total passenger transport market share and 1% of the total freight transport in 2015 to 13% for passenger transport and 14% for freight transport by 2020.

(2) Railway Development in Southeast Asia

The Vietnamese railway is a growing industry with ongoing and upcoming railway upgrading projects, but its absolute market size remains small compared with those of China, India, and some of the other ASEAN countries. To overcome this limitation, in the long-term, the country must explore strategies for regional cooperation, looking beyond its borders for export markets.

The Association of Southeast Asian Nations (ASEAN) marked its 50th anniversary in 2017. Southeast Asia's economies are projected to grow at an annual average of 5% until 2020, by when the consumer spending power of its 625 million people is expected to reach USD 2.3 trillion. A flurry of activities building the region's railway network is underway, sparked in part by China's Belt and Road Initiative (which will cut through Vietnam). Linkages of the Southeast Asian railway network will be a paradigm shift for the region. Apart from removing bottlenecks in the flow of goods between China and Southeast Asia, it has the potential to increase intra-regional trade.

Various HSR projects being undertaken across Southeast Asia could also create a powerful system for social and economic exchanges. Singapore and Malaysia have proposed a HSR project between the two nations while Indonesia is planning its own between Jakarta and Bandung. After years of delay, the China-Laos-Thailand high speed railway project is reportedly targeted to start construction in October 2018.

(3) Regional Cooperation through Division of Roles

Naturally, with projects of such enormous scale like international high speed rail network, implementation is not always going to be smooth. Differences in construction standards and technical levels, rivalries between contractors, financing and environmental concerns, and disagreements among multiple jurisdictions can be listed among possible issues. Notwithstanding these challenges, railway expansion in the region is an opportunity for Vietnam to establish its place in the industry and expand its market by cooperating with neighboring countries, particularly ASEAN member states.

ASEAN Free Trade Area (AFTA), a trade bloc agreement among the ten ASEAN member states (Brunei, Indonesia, Malaysia, the Philippines, Singapore and Thailand, Vietnam, Laos, Myanmar and Cambodia), has now been virtually established, supporting local manufacturing by eliminating most intra-regional tariffs. Earlier this year, eleven Asia-Pacific countries (Australia, Brunei, Canada, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore and Vietnam) signed the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), a multilateral free trade agreement negotiated by the remaining nations of the Trans-Pacific Partnership notwithstanding US's withdrawal. The Regional Comprehensive Economic Partnership (RCEP) currently being negotiated between ASEAN and six of its main trading partners – China, Japan, South Korea, India, Australia and New Zealand – will promote wider free trade in goods and services as well as enhance investments. Economic potential of Southeast Asia is ripe, and institutional framework is shaping up to move things right along.

Capitalizing on new opportunities offered by these policies, ASEAN, with international partnership and support, should encourage a system in which each country would specialize in a particular part or process of the industry to create a mutually beneficial division of roles. Vietnam's manufacturing and trade industries show great potentials with abundant, increasingly well-educated, hardworking workforce. A relatively young population also adds to Vietnam's strength and growing potentials. Specialization based on division of roles would also allow relatively smaller countries like Vietnam to compete with more economically powerful nations such as China and India. Assuming that many countries will be vying for the same opportunities, Vietnam should move quickly to maximize its share in the supply chain. The earlier the country's railway system can be modernized, and capacity development advanced, the better. When products become sufficiently competitive in the international market, export of specialized products beyond ASEAN borders should be targeted.

6.2.4 Capacity Building

(1) Institutional Framework and Policies

In order to enable the abovementioned division of roles and secure its areas of specialization, Vietnam's technical human resource capacity must be strengthened to advance beyond simple assembly or routine machine operation and generate international competitiveness. The important idea in skills enhancement is to continually aim for mastering the next level, something slightly more advanced than one's current capability. Technical transfer through structured curriculum and practical training is needed, and for industry development, institutional support through effective policies is crucial in creating an environment to facilitate such technology transfer.

<u>Government Policies on Railway Industry Development</u>:
Measures such as corporate tax exemption and reduction, tax deduction for machinery purchases, subsidies for R&D, and the like, are important in accelerating investment in private manufacturing companies. Emphasizing the Vietnamese government's commitment to revamping the country's railway system, the revised Railway Law was passed last year and has just come into force in July 2018. The 2017 Railway Law prescribes railway infrastructure planning, investment, construction, protection, management, maintenance and development, applicable to both domestic and foreign organizations. It even devotes a newly added chapter on HSR. Though it remains to be seen how effective these regulations will be, it is hoped that it will provide a well-focused national campaign to promote corporate and capacity development surrounding the railway industry.

<u>Conditions for Foreign Investment</u>:
Favorable policies and conditions (e.g., in financing, tax, land, labor regulations) are essential to attract foreign direct investors. Guarantee of profit is important in securing their investment.

<u>Joint Venture</u>:
Manufacturing companies of railway parts can be established as a joint venture with Japanese firms to encourage an effective technology transfer. Advantages of working with Japan include the country's high level of technology and the fact that Japan is one of the biggest foreign direct investors in Vietnam. It was recently reported that the majority of Japanese investors in Vietnam are planning to expand their business activities in the country.

(2) Technical Transfer in Phases

Because large-scale capacity building takes time, phased approach supported by foreign direct investment should be taken. Explained below are progressive steps for skills transfer, based on abovementioned concepts. The general idea is to start with simple assembly, study the individual parts through the assembly process, choose technically easier parts to start manufacturing, then slowly move up to more complicated parts as the overall technical level increases. The eventual goal is to handle operations and maintenance of rolling stock domestically to reduce reliance on imported parts.

1) Assembly of Rolling Stock

- Establish facilities in the country for assembly and dismantling of rolling stock. This is the facility of the railway maintenance factory itself.
- During assembly and dismantling processes, study the parts carefully to explore the feasibility of domestic manufacturing.
- If domestic manufacturing of certain parts (e.g., glass) is deemed feasible and advantageous, establish manufacturing companies – if possible, joint venture with, e.g. Japan and receive training from international experts.

Below steps are implemented ideally in a joint venture.

2) Manufacturing of Interior Parts

- Based on acquired knowledge from assembly process, start with manufacturing of parts that are relatively simple from a technical perspective, such as glass, seats, hanging straps, etc.
- Keep in mind that even if technically simple, close attention must be paid to safety regulations and different international standards.

3) Manufacturing of Electrical Parts

- Based on acquired knowledge from assembly process, start with manufacturing of simple, non-essential parts.
- Set up horizontal or vertical division of labor with other ASEAN countries.
- Long-term goal is to acquire design technology through training from international experts gradually.

4) Manufacturing of Machinery Parts

Ideally, in a joint venture company:

- Start with manufacturing of simple, non-essential parts.
- Focus on materials that can be produced/obtained locally, e.g., metal, plastic, coke.
- Government policies should encourage technical training programs.

Parts manufactured in joint venture corporations are anticipated for not only domestic use but also for exportation to Japan and third countries.

6.2.5 Conclusion

Vietnam's railway industry is facing a big opportunity. The government has announced initiatives and new regulations for reinventing its existing system. Regional/international investments in rail lines of Southeast Asia and developments in trade agreements are bringing economic changes. If played well, Vietnam could revive its railway industry, which could then effectively propel growth in railway-related supporting sectors and export economy. Keeping in mind that with opportunity comes competition, Vietnam should move quickly to solidify economic cooperation with ASEAN and neighboring countries and strengthen skilled domestic workforce. For technical transfer, Vietnam should take advantage of Japan's world-class railway technology and their eagerness to invest in Vietnam.

7. Preliminary Economic Evaluation

This chapter has been removed because of confidential information.

8. Project Scheme and Financing Options

8.1 Project Scheme Analysis

8.1.1 Fiscal Situation of the Vietnamese Government

In Vietnam, public projects that meet certain requirements, such as policy priorities, investment amounts and sectors must be listed in the Mid-Term Public Investment Plan (MTIP)[1]. The latest MTIP covers 5 years between 2016-2020, and the next MTIP (2021-2025) is scheduled to be updated in 2020. In the current MTIP, an amount of 20.2 billion VND has been allocated for project preparation. Once the project investment policy is approved by the National Assembly, the construction cost shall be allocated in the next MTIP. According to Ministry of Transport of Vietnam (MOT), the most prioritized project in the current MTIP is the North-South Expressway. The total investment is estimated at about 13.8 billion USD (VND312 Trillion). The whole section is expected to be operated in 2030.

The total expenditure budget and investment budget of the Government, and the investment budget of MOT and HCMC in 2018 are shown in the table below.

Table 8.1: Investment Budget of the Government and PCs (2018)

Budget	Amount (Billion VND)	Amount (Billion USD)	Amount (Billion JPY)
State Budget Total	1,523,200	67.9	7,326.59
State Budget for Investment Total	372,036	16.6	1,789.49
State Budget for Investment Int'l	52,568	2.3	252.85
MOT Investment Budget Total	21,230	0.9	102.11
MOT Investment Budget National	8,444	0.4	40.62
MOT Investment Budget Int'l	12,785	0.6	61.5
HCMC Investment Budget Total	41,537	1.9	199.79
HCMC Investment Budget National	38,673	1.7	186.02
HCMC Investment Budget Int'l	2,864	0.1	13.78

Source: Vietnamese Government decision (2131/QĐ-TTg 2018)

The expenditure plan for the Vietnam in 2018 is about 67.9 billion USD, which is equivalent to the initial investment cost of HSR project in Two-step Case. Given the fact, it is found that implementing the HSR project will be a significant burden for the Government. Among the expenditure mentioned above, the annual investment budget (including ODA) is about 16.6 billion USD. Moreover, the investment budgets of MOT and HCMC People's Committee (implementing agency of urban railway development project) are about 0.9 billion USD and 1.9 billion USD, respectively.

In addition, the Government is implementing policies to limit their external borrowing to 65% of the GDP. The management status of external debt in the last 5 years is shown in Table 8.2.

[1] Article 14 of the Public Investment Law and Decree No. 86/ND-CP (Decree of the Government defining the functions, tasks, powers and organizational structure of the Ministry of Planning and Investment)

Table 8.2: External Borrowing Status and Borrowing Ceiling of the Government

	GDP (Billion USD)	Public Debt Ratio
2013	171	54.5%
2014	186	58.0%
2015	193	61.0%
2016	205	63.6%
2017	221	61.3%

Source: JICA Study Team

The table above shows that the public debt ratio has been moving marginally below 65% in the last few years. Borrowing from overseas has also been limited to 1,500-1,700 million USD (These targets are not strictly observed on Disbursement basis).

8.1.2 PPP in Vietnam

Although there are huge needs of infrastructure investment in Vietnam, the fiscal condition of the Government is quite tight, and it cannot secure enough budget to fulfill those needs. To cope with the issue, the government is promoting Public-Private Partnership (PPP) Type-Project for which private funds are mobilized. The Government has established several decrees relating to PPP, and the latest one is Decree No. 63 of 2018, regarding promotion of PPP. Currently, this decree serves as the basis to develop and implement PPP projects in Vietnam. Also, the Government is discussing and preparing for the establishment of PPP act in order to clarify its legal basis as well as to solve inconsistency with the existing laws.

Despite this situation, there has been little PPP projects procured competitively under Decree No. 63 (and Decree No. 15, which is the predecessor of Decree No. 63), due to reasons such as conflicts with existing laws and regulations, a complicated procedure of application and approval, unclear benefits to the government and people's committees, and a lack of capacity and experience of public officers. Therefore, private-initiated "unsolicited proposals" have been preferred because it can avoid complicated procedures and perhaps competition among bidders. However, the number of unsolicited proposals have not been so large because it still requires land acquisition, financial viability, transparency and compliance.

In conclusion, the Vietnamese Government has established PPP legal framework and project supporting mechanisms such as VGF (Viability Gap Funding), but it is not working well yet.

8.1.3 Project Modality

With regard to project scheme and project executing entity, three options can be considered based on experiences of foreign countries and observation of the current conditions in Vietnam in terms of railroad operation and legal framework of PPPs.

- VNR becomes the project company, develops and operates the project.
- Private enterprises establish a project company, which develop and operates the project.
- VNR and private enterprises establish a project company, which develop and operates the project.

The advantage of involvement of private enterprises are as follows:

- It may help the government to decrease its (direct) expenditure
- It may realize cost reduction and service improvement by using technologies and know-how of private enterprises.
- Reduction of project cost may shorten the project construction period, which will enable earlier commencement of service provision.

On the other hands, there are following challenges with regard to involvement of private enterprises:

- Private companies may not participate due to ridership risk, land acquisition risk, and profitability, etc. which most private enterprises cannot control.
- There is no private enterprise who has experience running a high speed rail business in Vietnam.

As to the point No. 2 mentioned above, in particular, it is considered essential to receive cooperation and/or support from foreign entities who has an experience of high speed rail running business, to supplement lack of technology and experience of Vietnamese enterprises and organizations. For whichever options, it is essential to go through public procurement process and ensure competition and transparency, when the government select private companies which will be involved in the project.

8.2 Project Financing Options

As mentioned in the previous chapter, three options can be considered as project scheme and the funding source are broadly classified into government source and private source. The former can be further classified into the government's own revenue such as tax and domestic borrowing, and foreign borrowing including ODA. The pros and cons of each financial options are summarized in the following table:

Table 8.3: Pros and Cons of Financial Options

	Pros	Cons
Government (Tax Revenue)	- Simple and speedy procedure	- Limited availability of funds
Government (Foreign Borrowing)	- Expanded availability of funds - Concessionality (Low interest rate, long tenor, etc.)	- Complicated procedure - Exchange risk
Private (Commercial Funding)	- Expanded availability of funds - Mitigation of government's fiscal burden - Innovation by private sector	- More complicated procedure due to insufficient PPP system - Funding scale and scope is limited - Interest rates are higher than government procurement

Source: JICA Study Team

Among these, regarding the government's own budget, although the amount itself has been including due to the country's economic growth, the head room for this project investment is quite tight in consideration the existing investment programs. Also, regarding foreign borrowing, the debt amount is almost reaching the upper ceiling of 65%, which is determined by the national assembly; it means the government cannot easily increase its foreign borrowing under the status quo. In such a situation, it is understandable that government has a high expectation for mobilization of private funds, however, such an optimism should be avoided because it is also not easy, the reasons being that there are many hurdles to be overcome to adopt PPP or attraction of private investment as discussed in the previous chapter, on top of the fact that the investment amount is almost equivalent to the government's annual expenditure.

Because of these reasons, it is difficult to show a clear answer to this question under this study framework. However, one thing which is clear is that it is unrealistic to depend private sector to shoulder much of the investment cost. Therefore, as is obvious, the government should secure the budget for construction from foreign borrowing including ODA and/or its own source. It is recommended that the government shall take an approach to seek mobilization of private funds (or mitigate the government expenditure) under the precondition that the primary source of the investment cost should be the government. Lastly, it is worth pointing out that the fiscal sustainability and affordability are two of key factors to be considered, in addition to technical aspects, in determining the construction schedule.

8.3 Experiences of Existing HSR Project

8.3.1 Taiwan HSR

(1) Project Overview

Taiwan HSR, commonly known as "Taiwan Shinkansen," is the first case of export of Japan's Shinkansen. It is a pioneering case of utilizing private finance in Taiwan. A Build-Operate-Transfer (BOT) procurement approach was adopted where the private sector would build and finance the project without any government support.

In October 1996, the Taiwanese government made a public notice of the Taiwan HSR. Two teams, The Taiwan HSR consortium which partnered with German and French team, and the China HSR consortium, which partnered with Japan, passed the primary screening. As a result of the bid held in September 1997, the Taiwan HSR consortium won the preferential negotiation right[2]. In May 1998, the Taiwan High Speed Rail Co., Ltd. (hereinafter THSRC), a project company incorporated by five Taiwanese companies, was established. In July 1998, the THSRC agreed with the Taiwanese government about construction and 35-years-operation of the HSR[3].

The construction work was carried out in vertically integrated and the THSRC was responsible for both E&M and civil work for whole area except for one section in Taipei. Construction began in August 2000, and the Taiwan HSR, 345 km of distance from Taipei to Kaohsiung, commenced the commercial operation in January 2007.

The project overview of Taiwan HSR is shown in the table below.

Table 8.4: Project Overview of Taiwan HSR

Project company	Taiwan High Speed Rail Corporation Ltd. (THSRC)
Length	345 km (Taipei – Kaohsiung) *extended by 10 km in July 2016
Project cost	513.3 billion NT$ (about 1.8 trillion JPY)[4]
Construction period	8 years and 6 months (signed a contract in July 1998[5], operation commenced in January 2007)
Operation period	35 years *extended to 70 years in July 2015 (till 2068)

Source: Taiwan HSR HP

[2] There are various opinions that THSRC was selected. Although one of the reasons was its low price, another reason was that the proposal by Taiwan HSR consortium did not require the disbursement by the Taiwanese government at the construction stage was attractive for the government. In contrast, China HSR consortium suggested that the investment of 149.5 billion NT$ is required by the government. (China Economy, 2005)

[3] After the agreement, THSRC had the right to decide the equipment including vehicle. At the competition stage, THCRS partnered with Germany and France, however because of the derailment and rollover accident of ICE in Germany and the change in the environment surrounding the project, Shinkansen was also added to THSRC's choice. As a result of the competition between the Japan's consortium and the Germany and France union, Japan gained preferential negotiation rights in December 1990, and the official contract was reached the following year. More detail is referred to "Transport Policy Studies Vol. 6 No. 1 (2003)"

[4] Among the total project cost, the private sector's project cost was 406.6 billion NT$ (approximately 1.5 trillion JPY).

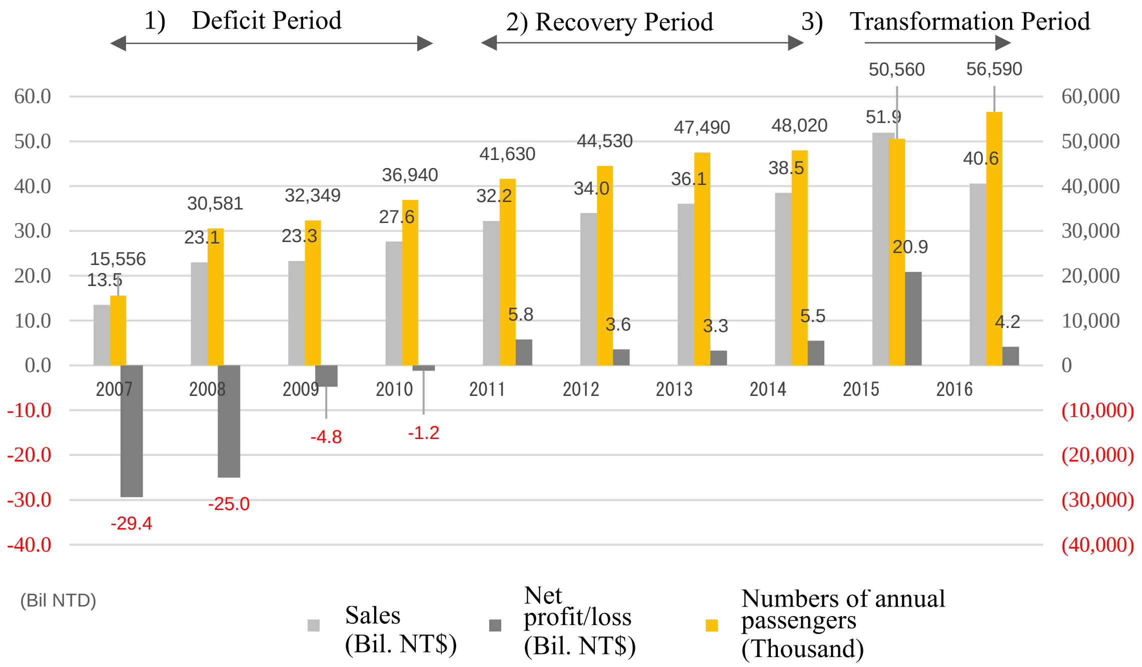
[5] Since a major earthquake in Taiwan occurred in September 1999, the design and construction of civil work was necessary to be reviewed and THSRC finally signed a contract in March 2000 and started the construction in August.

(2) Business History

The history of business situation of THSRC is explained separately in the following three periods.

1) Deficit Period: when the loss continued since the commencement of operation
2) Recovery Period: when the deficit turned into surplus and the number of passengers increased
3) Transformation period: when the government-led restructuring was proceeded.

The figure below shows the trends of sales, net income (loss) and the number of annual passengers.



Note: Government reimbursement of statutory discount tickets is included in the net profit of 2015.
Source: JICA Study Team based on THSRC Annual Report

Figure 8.1: Trend of Sales, Net Income (loss) and the Number of Annual Passengers of THSRC (2007-2015)

1) Deficit Period (2007-2010)

In the first year of operation, operating revenue was about 4 billion NT$ and it recorded a loss of 29.4 billion NT$ after the deduction of depreciation and interest cost. In the following year, THSRC initially expected about 240,000 passengers per day. However, it ended up to be only about 80,000 people actually due to optimistic demand forecast. While the number of passengers was sluggish, depreciation and interest cost of billions of project was heavy, and the cumulative deficit expanded to 73.5 billion NT$ in 2010. This amount was about 70% of the capital of THSRC. THSRC finally became in danger of financing and consulted with financial institutions. They agreed to get refinance of 382 billion NT$.

2) Recovery Period (2011-2014)

THSRC got surplus for the first time after the commencement of operation in 2011 because of a steady increase in the number of passengers. As described later, the increase in the number of passengers was mainly due to the improvement of railway service by THSRC. The main performance indicators (hereinafter KPI) in the year are shown as follows.

- Number of passengers: 41.6 million (+12.7% over the previous year)
- Loading factor (passengers-km/seat-km): 51.6% (+2.6% over the previous year)
- Train services per year: 48,553 (+3.3% over the previous year)
- Punctuality: 99.86% (+0.64% over the previous year)

It can be seen that each indicator has greatly improved since 2010. For example, the punctuality improved by 0.64% over the previous year in 2011 while it had been around 99.1% to 99.2% until 2010 since the commencement of operation. According to the THSRC annual report (2011), in addition to the improvement of ticket sales methods (sales at convenience stores and service release of mobile phone reservation system) and of access to the station (increase of free shuttle bus service from the city to the station and development around the station ensuring mobility) were considered as the reason for the passenger increase. From 2011 to 2014, the number of passengers steadily increased by about 4.4% of an annual average

3) Transformation Period (2015-)

THRSC faced a financial difficulty because of cumulative deficit and prosecution by some shareholders for delay payment of dividends and repurchase of preferred stock. In order to avoid the collapse, THSRC submitted a financial improvement plan to the government, and the plan was approved in July 2015. THRSC reduced its capital stock by 60% of 65.1 billion NT$ and got cash injection of 30 billion NT$ by the government. As a result, the government's stake increased to 63.7%. Hence, the concession period was extended for 35 years until 2068 in order to reduce the burden of depreciation expenses per year.

In July 2016, the first extension was realized after commencement of operation, and the line from Taipei Station to Nanko Station was opened. Furthermore, THSRC was listed on the Taiwan Stock Exchange in October. With the government-led restructuring, extension, and listing, it will draw attention whether the HSR business can be put on track in the future.

(3) Lessons Learned

Lessons learned from Taiwan HSR are as follows.

- Optimistic revenue plan

Demand forecast was too optimistic at the planning stage as it is obvious from the fact that the number of passengers per day was expected to be about 240,000; however, was only about 80,000 actually. Besides, the fact that the distance to the city area was far from each station and that the transportation system to the station was not enough were also the reasons why the number of passengers was sluggish.

- Heavy cost burden due to vertically integrated construction

Since THSRC carried out civil work except for a section in Taipei, the amount of capital investment was huge and the annual depreciation and interest cost placed pressure on the profits. This was a main factor that made it difficult for THSRC to continue the business.

- Improvement of operation services

In order to improve access to each station, THSRC increased the number of free shuttle buses from the city area to the station and improved mobility around the station. Also, the selling method of tickets and punctuality were improved in order to improve the convenience of railway users.

The series of initiatives aimed at improving the operation services had resulted in an increase in the number of passengers, and a surplus.

- Huge financial injection by the government

Restricting the government burden to land acquisition and civil work in a section only helped to reduce the fiscal burden of the government at the beginning of the project. However, the private operator could not continue the business alone. As a result, government-led restructuring was done and huge financial injection by the government was necessary to compensate.

8.3.2 UK HSR

(1) Project Overview

High Speed 1 (hereinafter HS1)[6] is a high-speed rail with a total length of 109 km between London and Channel Tunnel. In February 1996, London and Continental Railway (LCR), a business consortium of private enterprises, acquired the construction work and O&M concession of HS1. However, it turned out that the demand forecast by consultants appointed by the UK government was overly optimistic, and LCR was unable to raise funds by itself. Therefore, the UK Government decided to expand financial support, such as guaranteeing loans of 3.75 billion pounds and payment of tolls, in addition to promised approximately 1.7 billion pounds of financial assistance mainly subsidies[7]. In accordance with the prospect of fund procurement, construction began in October 1998. The 1st section of 74 kilometers reaching to Channel Tunnel was opened in September 2003, and the whole section has been commercial operation in November 2007.

The project overview of HS1 is shown in the table below.

Table 8.5: Project Overview of High Speed 1

Project company	London and Continental Railway (LCR) *The business was transferred to HS1 Ltd. later
Length	109 km (London - Channel Tunnel)
Project cost	5.8 billion pounds (about 870 million yen)[8]
Construction period	11 years and 9 months (signed a contract in February 1996, commenced the operation of whole section in November 2007)
Operation period	30 years[9]

Source: JICA Study Team based on research document of British Parliament “Railway: HS1” (2011)

(2) Business History

The history of the business situation of HS1 is explained separately in two periods: 1) Initial Period of commencement of operation and (2) Stable Period.

1) Initial Period (2003-2009)

In UK, each division of passenger transportation and infrastructure maintenance are separated, and a railway management type of vertically separated was adopted since the former British National Railway privatization in 1994. Under this system, infrastructure maintenance and train operation are carried out by different entity. However, LCR was responsible for O&M of both infrastructure (entrusted to Network Rail) and international trains (Eurostar) entirely[10].

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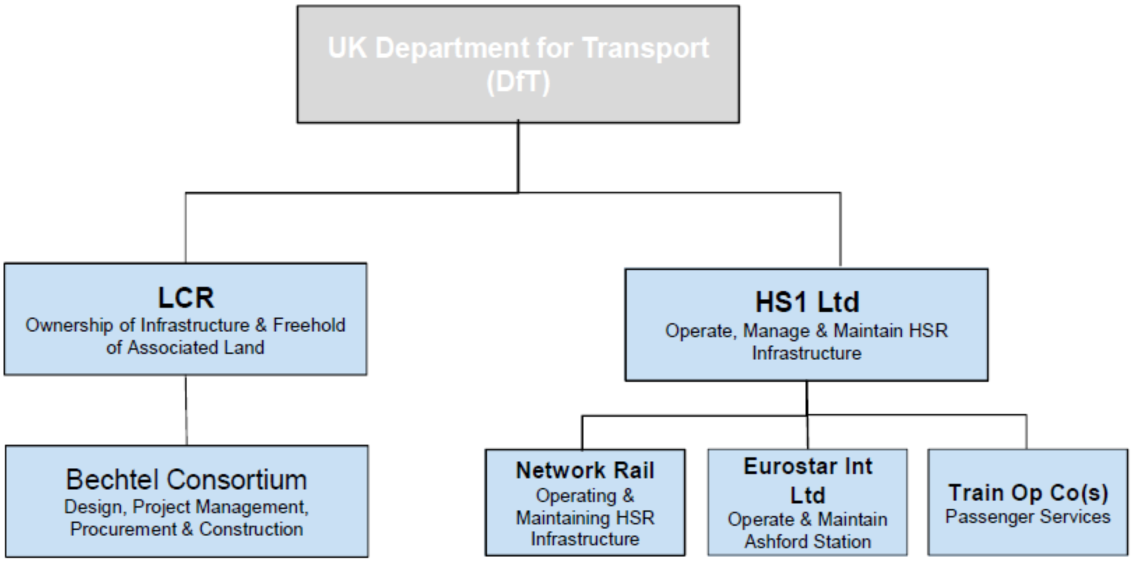
6 Before the whole section was opened, it was called as Channel Tunnel Rail Link (CTRL).
7 In return for these guarantees, the UK Government has agreed to receive 35% of HS1's operating revenue.
8 The total cost at the time of planning in 1997 was EUR 4.17 billion.
9 It was shortened from 999 to 90 years in 1998, and now it is 30 years because the project company has changed.
10 As for domestic railway, the Southern Railway is responsible for train operation under franchise agreement.

Direct train operation between conventional and high speed rail line started in 2009[11] and domestic freight transportation was expanding. In a meanwhile, LCR fell into serious financial difficulties. Debt amount of LCR was huge due to billions of construction project and deficit of the Eurostar (UK)[12] under LCR continued. The UK Government, who severely analyzed that the long-term financial expenditure could be continued, decided to implement financial restructuring of LCR and put it under the government in 2009.

2) Stable Period (2010-)

After the financial restructuring of LCR, ownership and management of infrastructure were completely separated and the infrastructure came to be owned by the UK Government substantially. Meanwhile, O&M of infrastructure and international railway were transferred to HS1 Ltd. as shown in below figure. As a result, HS1 escaped from the huge debt of infrastructure construction, and it enable the entity to set royalty fee on a commercial basis[13].

In addition, the UK government promoted selling the business of HS1 to the private sector. It aimed to reduce the financial burden of construction of HS1 and of writing off the LCR's debt.[14]



Source: AECOM Australia Pty Ltd. "High Speed Rail Study" (2013)

Figure 8.2: Business Scheme of HS1

11 Hitachi delivered high-speed railway vehicles for HS1, providing vehicle maintenance services.
12 As of the end of December 2008, LCR's debt amounted to 6,268 million pounds and the operating deficit of Eurostar (UK) amounted to 2,578 million pounds respectively.
13 European Commission "Restructuring of London & Continental Railways and Eurostar (UK)" (2009)
14 In November 2010, a consortium of Canadian investment companies: Borealis Infrastructure and the Ontario Teacher Pension Fund acquired a 30-year O&M concession for 2.1 billion pounds. In addition, in September 2017, UK infrastructure funds acquired all shares, and Japan Infrastructure Initiative Co., Ltd., which Hitachi, Ltd. participates in, invested 75 million pounds on the related funds.

(3) Lessons Learned

Lessons learned from the HS1 project are as follows.

- Excessive demand forecast

Due to the excessive demand forecast at the planning stage, it became a situation in which selected company were unable to procure funds. Additional fiscal support by the government was necessary for the construction of HS1, and as a result, most of the project cost was covered by subsidies and bond guarantees of the UK Government.

- Heavy cost burden due to vertically integrated construction

In this project, capital investment amount was huge since the project company procured whole civil work. Coupled with huge liabilities after the commencement of operation, it became difficult for LCR to sustain its business without continued support by the UK government.

- Separation of management and ownership

After the financial restructuring of LCR, ownership and management of infrastructure were completely separated. HS1 escaped from the huge liability of infrastructure construction and it enable the entity to set royalty fee on a commercial basis.

9. Preliminary Financial Analysis

This chapter has been removed because of confidential information.

10. Operation and Effect Indicators

10.1 Operation Indicators

The followings are proposed as operation indicators, which quantitatively show operation status of the Project. It is recommended for the operator of the Project to monitor the indicators annually and report the monitoring results to the Ministry of Transport, relevant development partners, investors and lending institutes with its annual reports as well as to publicize the status to the public. The operator is encouraged to advertise the high reliability of the high speed rail service and to induce shifts of passengers from other transport modes for more customers of the service. Definitions and targets of the operation indicators are shown in Table 10.1 and Table 10.3, respectively.

<u>Basic Operation Indicators</u>

1) Transportation volume
2) Number of running trains
3) Operation reliability of rolling stock

<u>Indicators on Operation Quality</u>

4) Operation reliability

Table 10.1: Proposed Operation Indicators

Indicator	Definition	Remarks
1. Transportation Volume	Annual passenger × kilometer (million)	As basic indicators, operators are encouraged to monitor and report the results to the Ministry of Transport, relevant Development Partners, Investors and Lending Institutes as we as to publish to the public.
2. Number of Train Services	Number of annual train services (one-way trips/year)	
3. Operation Rate of Rolling Stock	Number of running cars × day / Number of cars owned × Operation days of the year (%)	
4. Operation Reliability	Number of trains departing the origin stations within 15 minutes of the scheduled time / Number trans scheduled for the services (%)	* Delays/suspensions of force majeure are not counted. * Promotion for larger number of passengers by appealing high reliability of the high speed rail service

Source: JICA Study Team

10.2 Effect Indicators

The followings are proposed as effect indicators, which quantitatively show effects caused by the Project implementation. Same as operation indicators, the operator of the Project is recommended to monitor on the indicators and report the monitoring results to the Ministry of Transport, relevant the development partners, investors, lending institutes and the public with its annual reports. Definitions and targets of the effect indicators are listed in Table 10.2 and Table 10.4, respectively.

5) Transportation volume (same as Operation Indicator 1)
6) Travel times of specific sections (hours, minutes and seconds for a one-way trip)

Table 10.2: Proposed Effect Indicators

Indicator	Definition	Remarks
5. Transportation Volume	Annual passenger × kilometer (million passenger*km)	As a basic indicator, operators are encouraged to monitor and report the results to the Ministry of Transport, Development Partners, Investors and Lending Institutes as we as to publish to the public
6. Travel times of specific sections	Average travel times of sections among specific stations (hours: minutes : seconds)	

Source: JICA Study Team

Table 10.3: Targets of Operation Indicators

Indicator		Target								
		Two-step Case				Five-step Case				
1. Transportation Volume (Annual passenger × kilometer in millions)		2030	2040	2050		2030	2040	2050	2060	2070
		7,167	67,466	72,755		138	2,244	7,015	14,800	82,892
2. Number of annual train services (both-ways trips/year)	Section	Ngoc Hoi - Vinh	Vinh - Da Nang	Da Nang - Nha Trang	Nha Trang - Thu Thiem	Ngoc Hoi - Vinh	Vinh - Da Nang	Da Nang - Nha Trang	Nha Trang - Thu Thiem	Long Thanh - Thu Thiem
	2030	26,280	---	---	26,280	---	---	---	---	14,600
	2040	55,480	52,560	52,560	56,940	33,580	---	---	---	20,440
	2050	62,780	56,940	56,940	65,700	43,800	---	---	36,500	---
	2060	---	---	---	---	49,640	---	24,820	59,860	---
	2070	---	---	---	---	77,380	77,380	77,380	77,380	---
3. Operation Rate of Rolling Stock (%)		2030	2040	2050		2030	2040	2050	2060	2070
		89.3%	92.3%	92.5%		73.3%	85.9%	91.6%	90.7%	91.8%
4. Operation Reliability (%) *		98%								

(Note) *: Referring an example Taiwan High Speed Rail (Annual Reports 2007-2016, Route length; 345 km - 22% of the North-South High Speed Rail Project in Vietnam).
Taiwan High Speed Rail has achieved higher rate than 99% of trains departing the origin stations within five minutes, within ten minutes for 2007, of the scheduled time to total trains scheduled for the services.
Source: JICA Study Team

Table 10.4: Targets of Effect Indicators

Indicator	Target							
	Two-step Case			Five-step Case				
5. Transportation Volume (Annual passenger × kilometer in millions)	2030	2040	2050	2030	2040	2050	2060	2070
	7,167	67,466	72,755	138	2,244	7,015	14,800	82,892

Indicator	Ngoc Hoi - Thu Thiem		Ngoc Hoi - Vinh		Vinh - Da Nang		Da Nang - Nha Trang		Nha Trang - Thu Thiem*		Long Thanh - Thu Thiem
6. Average travel times of sections among specific stations (hours : minutes : seconds)	Local	Express	Local	Express	Local	Express	Local	Express	Local	Express	Local
	7:15:00	5:20:00	1:21:00	57:30	1:59:00	1:24:00	2:11:00	1:34:00	1:38:00	1:18:30	0:11:00

(Note) *: Travel time of the express for the section between Nha Trang - Thu Thiem is estimated with assumption of stopping at Long Thanh Station.
Source: JICA Study Team.

11. Qualitative Analysis of the Project Effects

11.1 Effects of the Project Implementation and Their Quantification

Various types of effects will occur as the results of the implementation of the Project as shown in Table 11.1. A preliminary economic evaluation, i.e., a benefit-cost analysis, is conducted as described in Chapter 7 of this report, counting “Saving in vehicle operation cost (VOC),” “Saving in travel time,” “Reduction of CO_2 emission” and “Reduction of traffic accidents” as benefits of the Project.

Table 11.1: Effects by the Implementation of the North-South High Speed Rail Project

Direct/ Indirect	Beneficiary	Benefits		Benefits not counted in the preliminary economic				Quantification
		Category	Contents	Not dependent on traffic volume	Non-market value	Impacts	Possibility of Quantification	Methods
Direct Effect	Service Users	Use of the Services	Saving in VOC				○	refer to Chapter 7
			Saving in travel time				○	refer to Chapter 7
			Reduced traffic accidents				○	refer to Chapter 7
			Improved convenience		○		△	Contingent Valuation Method (CVM)
	Wayside and Local Society	Environment	Reduced GHG emission				○	refer to Chapter 7 Travel cost method Hedonic approach CVM Alternate method
			Creation of scenic beauty/ aesthetic improvement	○			△	
			Reduction of noise		○		△	
			Ecosystem preservation		○		△	
		Living of residents	Amplified living sphere/inter-action opportunities	○	○		○	Travel cost method Hedonic approach CVM Alternate method
Indirect Effect			Improved access to public services	○	○		△	
			Improved access to recreational facilities	○	○		△	
			Local culture promotion/ Preserved traditional culture	○	○		△	
			Alternative transport measures in events of disasters	○	○		△	
			Secured disaster prevention space	○	○		△	
		Regional Economy	Demand creation by constriction projects	○		○	○	Input-output analysis model Regional econometric model Computable Urban Economic Model/ Land use transportation model Spatial applied general equilibrium model
			Employment/income generation	○		○	○	
			Improved business environment	○		○	○	
			Increased production by new location	○		○	○	
			Increased assets values	○		○	○	
			Attracted tourists/tourism promotion	○		○	○	
			Cost saving in public facility construction	○		○	○	
			Lowered price of goods and services	○		○	○	
	Country	Balanced national land development	Reduced regional disparity			○	-	* Note ○: Possible △: Difficult

Source: Prepared by JICA Study Team, referring to “Daft Guidelines for Evaluation of Investment in Road Development, Part II-Comprehensive Evaluation”, “Manual on Methods for Evaluation of Railway Projects” and “Basic Concept on Evaluation of Public Projects”, material for Study on Public Works System, Ministry Land, Infrastructure, Transport and Tourism, Japan

As high speed rail (HSR) projects incur huge amount of investment costs, quantitative analysis, which is more persuasive than qualitative analysis, is generally conducted for economic evaluation of HSR projects. Although most of benefits related to “Environment” and “Living of residents” are not quantified in the preliminary economic evaluation of conducted in this study, they can be quantified with the methods shown in Table 11.1. Adding the amount of these benefits to the amount of benefits related to “Use of the services for benefit-cost analyses, however, is not recommended, even if they are quantified, as there are possibilities of double counting.

As large-scale infrastructure development projects, such as HSR construction projects, contribute significantly to the development local and national economy in general, appraisal of these projects often accompany quantitative analysis after estimation of the increased production in the local and national economy with the models listed in Table 11.1. As the benefits of the increased production may contain the benefits derived from “Use of the services,” benefit-cost analyses, in which benefits of enhanced regional and/or national economy is counted, are conducted only with the benefits estimated by one of these models without adding benefits of the “Service Users.”

11.2 Expanded Cost-benefit Analysis

Methods for expanded cost-benefit analysis for HSR projects, with which estimated benefits of increased economic production can be added to the benefits of “Saving in VOC”, “Saving in travel time”, “Reduction of CO_2 emission” and “Reduction of traffic accidents”, are examined as the conventional cost-benefit analysis may not fully count of the benefits generated by the implementation of HSR projects.

The World Bank (WB) is developing methods with which the following benefits are estimated and added to the benefits of the conventional benefit-cost analysis through a technical cooperation project in China and other research activities.[1]

1) Agglomeration-induced productivity effects: Raised productivity and increased production through expansion of markets for input and products, and improved matching between producers and consumers
2) Employment effects: Increase/decrease of employment caused by changes in production and production areas
3) Tourism effects: Changes in number of tourists, days of stay and tourist expenditure. Changes in other areas and net increase or decrease have to be confirmed.

Department of Transport in the UK has developed a guidance for adding the following expanded benefits to the benefits of reduced transportation costs.[2]

1) Agglomeration effect: With investment in transport, firms and industries get closer (static clustering) and relocations of firms and industries are promoted (dynamic clustering), higher levels of productivity are attained.
2) Employment effect: With investment in transport, accessibility to jobs is improved, demands for labor at local levels are changed and employment opportunities are generated.
3) Induced investment Effect: With investment in transport, the attractiveness of location changes, results in net increments of investment.

[1] “Regional Economic Impact Analysis of High Speed Rail in China”, June 2014, the World Bank
[2] “Updating Wider Economic Impacts Guidance” September 2016, Department of Transport, UK

In Japan, when examining the adequacy of public project implementation, the influence of public works (construction work) on the regional economy and the national economy (production induction effect) may be estimated using an input-output diagram.

In the preliminary economic evaluation of the Project, the social discount rate for Vietnam is set as 7% and the EIRR is estimated at 7.27% taking account of only the benefits counted in the conventional benefit-cost analyses. As the EIRR is exceed the social discount rate a little, JICA Study Team cannot evaluate the Project as a project of high economic validity.

It would be recommendable to review the benefit-cost analysis by adding the expanded or wider economic benefits to the Project at the time of the feasibility study or before, while paying attention to double counting, referring to model / guidelines of the World Bank and UK Ministry of Transport and estimation examples of production induction effect of public works in Japan.

11.3 Qualitative Analysis

By the implementation of the Project, the effects described below will take place. The following benefits include those that can be quantified with the above-mentioned methods and not quantified in this study. Considering these qualitative benefits as well as the result of the preliminary economic evaluation, it can be said that the Project is socially and economically viable.

(1) Impacts on the Business Community

After the start of the operation of the HSR service, stations will be connected with 36 trains a day in 2030 and with 72 trains a day in 2040. Required times among the major stations are shown in Table 11.2 and will be reduced to less than one sixth of the times required for conventional rail travels. Travels by air to or from Hanoi take around three to four hours irrespective of distances between Hanoi and the city, and it cannot be said that all people can easily travel by air due to high prices of the tickets. As happened in Japan after the start of Shinkansen operation, HSR operation will cause large impacts on the business community.

In enterprises or public offices in Japan, if necessity arises for a meeting at the headquarters or branch offices along the Shinkansen, business persons or officials just decides the date and time of the meeting. They are quite sure that they can get to the Shinkansen station nearest to the place at a specific time if they go to their nearest Shinkansen station at a certain time. The Shinkansen network is an essential basic social infrastructure for the business persons or officials.

With the implementation of the Project, a backbone is formed, which connects the two largest city of Vietnam, namely, Hanoi and Ho Chi Minh City. The implementation will bring enormous impacts on the business world. It is expected that the implementation will contribute to strengthening the international competitiveness of Vietnamese industry by providing secured travel service for the business persons.

Table 11.2: Required Traveling Time among Major Stations by Conventional Rail and HSR

		Arrival station			
Departure Station	**Type of Rail**	**Hanoi (Ngoc Hoi)**			**(Unit: Hr. : Min. : Sec.)**
Vinh	Conventional	6:00:00	**Vinh**		
	HSR	0:57:30			
Da Nang	Conventional	15:56:00	9:56:00	**Da Nang**	
	HSR	2:23:00	1:24:00		
Nha Trang	Conventional	25:45:00	19:45:00	9:49:00	**Nha Trang**
	HSR	3:58:30	2:59:30	1:34:00	
Saigon (Thu Thiem)	Conventional	33:09:00	27:09:00	17:13:00	7:24:00
	HSR	5:20:00	4:21:00	2:55:30	1:20:00

(Note) Required traveling time by conventional rail is the traveling time by SE1 Train (Hanoi-Ho Chi Minh City, Departure time from Hanoi; 19:30).
Required time by HSR is the traveling time by HSR is the traveling time by the express service.
The traveling time for Nha Trang-Thu Thiem includes the stopping time (0:1:30) at Long Thanh Station
Source: JICA Study Team

(2) Promotion of Structural Reform for Specialized/Advanced Social Services

With the shorter traveling time required for inter-urban trips shown in Table 11.2, day-trip areas will be expanded. Expansion of the day-trip areas enables structural reform of specialized/ advanced social services. With the structural reform, costs for the facility construction, operation and maintenance will be saved and better quality of the services can be provided.

For example, regarding specialized/advanced medical facilities, conventionally each neighboring province is expected to individually prepare “cancer treatment medical center,” “brain disease medical center,” “cardiovascular treatment center.” With the expansion of the day-trip areas, the neighboring provinces can share these facilities, and the construction, operation and maintenance costs of the provinces can be reduced. Furthermore, the quality of the services of each specialized/advanced medical center are improved, and the residents of the provinces can receive more sophisticated medical services.

The structural reform can be applied to aggregation of specialized/advanced administrative services, financial services, etc.

(3) Intensification/Sophistication of Land Use in Front of the Stations and along HSR Route by Promoting Industrial Development and Attracting Industries

It can be foreseen that at HSR stations, HSR passengers and transit passengers of other transportation mode come and go, and commercial activities at and around the stations will be stimulated. Also, since access from surrounding cities is improved, it is presumed that the industries, especially commercial and service industries, will be promoted and developed, which in turn can promote the location of related companies. From this, the land use in front of the stations and along the HSR route will become intensified and sophisticated, leading to more effective use of the national land.

(4) Development of Regional Core Cities

Implementation of the Project will improve accesses among the cities, especially accesses to Vinh, Da Nang, and Nha Trang where express trains stop, and commercial/trading/economic spheres of these cities and the catchment areas the service facilities (including private-sector facilities) located in these cities will be expanded, Based on this fact, it is expected that these cities will develop as regional core cities. The development of these cities as regional core cities will lead to an increase in users of the HSR service.

However, instead of simply waiting for the development of the regional core cities as an effect of the development of HSR, it is important to promote strategic development of these cities with well-designed urban development programs and by attracting enterprises to these cities. It is hoped that the development of these regional core cities will lead to the balanced national land development and improvement of welfare level of the whole nation.

(5) Fostering the Unity of the Nation, Implementation of the Project as a Symbol, Raising Pride and the Patriotism of the People

This project connects north and south of Vietnam, and the two largest cities of Hanoi and Ho Chi Minh. Together with the construction of the North-South Highway, the Project is the centerpiece of infrastructure development for people and goods going back and forth in the country. The implementation of the Project will mobilize the people and activate exchange among citizens. As results, the implementation of this project will contribute to strengthening the sense of unity of the nation.

When the first Shinkansen line was built, it was a time for Japan to join the developed countries after reconstruction from the defeat in the World War II. It can be said that the Shinkansen project, together with holding of the Tokyo Olympic Games and construction of the Meishin Expressway, was one of the symbol projects that Japan was aligning shoulder with western countries. For Vietnam, the Project can be said to be a symbol project for becoming an upper-middle-income country like Thailand and Malaysia. Also, if the project is realized, consciousness will be shared that Vietnam has joined the country with advanced railway system, and that will stimulate the pride of the people.

Furthermore, it is expected that the fostered the unity and the raised pride of the people will lead to the rise of the patriotism of the nation.

12. Conclusion and Recommendation

12.1 The Framework of this Study

The Ministry of Transport (MOT) of the Vietnamese Government and its executing agency, the Project Management Unit (PMU) plan to submit the North-South HSR project to the National Assembly in 2019. For this purpose, the Vietnamese consultants, employed by MOT/PMU, will prepare the Pre-FS to be submitted to the National Assembly. This survey aims to support Vietnamese consultants in the preparation of the Pre-F/S.

Since this report summarizes the information provided or explained to the Vietnamese consultants as the responsibility of the JICA Study Team, this survey report focuses on concerns from the Vietnamese consultants. They, for example, have paid more attention to the feasibility analysis of cargo transport on the HSR line and on building the new railway for 200 km/h speeds and improving the railway facilities in the future.

12.2 The Conclusion of this Survey

Looking at HSR systems around the world, the point at which they become feasible to launch is correlated between GDP and population. Applying this to Vietnam's economic and social development, their high-speed railway should be launched around 2030. In this study, the demand forecast was conducted by keeping the existing railway, highway network, and improvement plan of aviation infrastructure in mind. The following points were recognized.

- Capacity shortage on the north-south corridor will occur after 2030 even if existing rail infrastructure is upgraded to a double-track. This shortage will increase year by year.
- HSR is a better solution than double-tracking the existing north-south rail corridor to meet the expected growth in demand.
- However, even if HSR is developed, a small lack of transportation capacity with the projected rail infrastructure will still exist. To cope with this issue, it is necessary to double-track the bottleneck sections.

This recommends the HSR as a newly constructed line to operate at 320 km/h operation and to open in 2030. It should be dedicated to passenger services, and developed from the sections at North and South with higher traffic demands, then extended to the whole line. Conventional lines on the other hand, are suggested to be improved single-lines to maximize transportation capacity and meet the passenger and cargo demand during the construction of the HSR. However, in sections with higher transport demands, double-tracked conventional railway lines could be constructed.

The economic benefits of the Project are calculated through comparison between conditions "with the Project" and those "without the Project." The estimated economic viability is given in Table 12.1, showing its feasibility.

Table 12.1: EIRR, B/C and NPV of the Project

Indicators	Economic Internal Rate of Return (EIRR)	Benefit-Cost Ratio (B/C)	Net Present Value (NPV, USD million)
	Removed		

Source: JICA Study Team

In order to examine the financial viability of the project, the JICA Study Team adopts the Financial Internal Rate of Return (FIRR). Several cases are examined to assess the financial viability of the project from several perspectives; in particular, the ratio of Capital Expenditure (CAPEX) to be borne by public and private sectors respectively. The financial burden on the Government in each case is also estimated. The conditions for the financial analysis are summarized below:

- Section: Hanoi-HCMC
- Type: High Speed Rail (Maximum Speed 320 km/hour)
- Project Period: Construction Period: 2020-2039 (Partial COD: 2030)
- Operation Period: Partial Operation: 2030-2039, Full Operation: 2040-2069
- Operating Entity: Special Purpose Company or SPC (Private Entity)

The results of the preliminary financial analysis are shown in the following table.

Table 12.2: Preliminary Financial Analysis Results

	Removed
FIRR	

Source: JICA Study Team

In terms of PPP feasibility, there is another critical point to be considered. According to the FIRR calculation assumption and results, construction periods are 10 years for partial opening and another 10 years for full opening (in total: 20 years). During that period, the cash flow on SPC will be negative, and accordingly, SPC will not be able to generate a profit which is not acceptable (Typically, the pay-back period for private investment is around 5 years). Therefore, the Government should provide subsidies to the SPC during the said period.

12.3 Consideration for Commercialization

The history of the railway industry has demonstrated that improvements of transportation convenience form new industries along the line routes that ultimately progress economic integration. This also spreads to the society along the railway, affecting the language of people and the content of education for the next generation. The Russian Siberian Railway and the Japanese railway network have both experienced this. In recent years, the Chinese Qinghai–Tibet railway and Spanish HSR seem to aim for the expansion of the unified cultural identity, and do not focus much on profitability.

As mentioned above, railways serve the essential function to integrate regions, but on the other hand, their construction requires enormous amounts of investments, so consideration must be given to the following matters regarding commercialization.

12.3.1 Clarification of National Goals

In the commercialization of the North-South HSR, it is necessary to identify the goals as a nation, while forecasting future events as much as possible.

- Development plans along the wayside
  National plan: Vietnam's 100-Year Vision
  Regional planning: Planning for new industrial cities and areas

- the international division of labor
  Identification of Vietnamese specialty areas and fields to be trained on the premise of competition and cooperation with other countries

- Grasping the strengths and weaknesses of Vietnam

From the following points of view, grasp the strengths and weaknesses of Vietnam and take appropriate countermeasures:
Society: human resources, education, common interests, religion, ideology
Economy: market, internal investment, foreign capital
Nature: geography, natural resources

12.3.2 Enlightenment for Local Companies and People

The HSR will play an essential role in setting the foundation for the continued development of the country. Vietnam as a nation or local companies should be responsible for its operation. When considering PPP, it is necessary to consider project schemes by hearing opinions from both Vietnam and foreign private enterprises which will be involved in the project. Also, the construction of HSR requires cooperation from citizens. Therefore, it is necessary to conduct outreach activities from the following viewpoints:

- Promotion of railway understanding
  The utility railway: Useful both for passenger and cargo, a symbol of national integration
  Conventional line: To improve regional traffic and cargo transportation
  High-speed rail: To maximize the functions as a dedicated passenger service

- Common Dreams
  HSR can contribute to achieving the following shared dreams of the Vietnamese people:
  Prosperous society: Society is enriched by new industries introducing domestic and foreign capital.
  Peaceful nation: Peace is maintained in cooperation with foreign countries.
  Diverse culture: Diversity is born by protecting tradition and adopting innovation.

12.4 Acknowledgment

The JICA Study Team expresses its sincere gratitude for the cooperation of the Vietnamese MOT, PMU, JV consultants represented by TEDI and related organizations, and to the Japanese government. The JICA study team expects that the HSR project will be realized and will significantly contribute to the development of the Vietnamese industry and culture in the near future.

Appendices

Appendix 1-1

Study on Semi-High-Speed Railway

Study on Semi-High-Speed Railway

1. Review Policy

(1) Speed

The *semi-high-speed railway* considered here corresponds to a railway operating at a maximum speed of 200 km/h on a line that is constructed for a maximum operating speed of 320 km/h. The purpose of the study is to examine the influence on demand, train operation, operation and maintenance work of this type of line.

(2) Railway Equipment

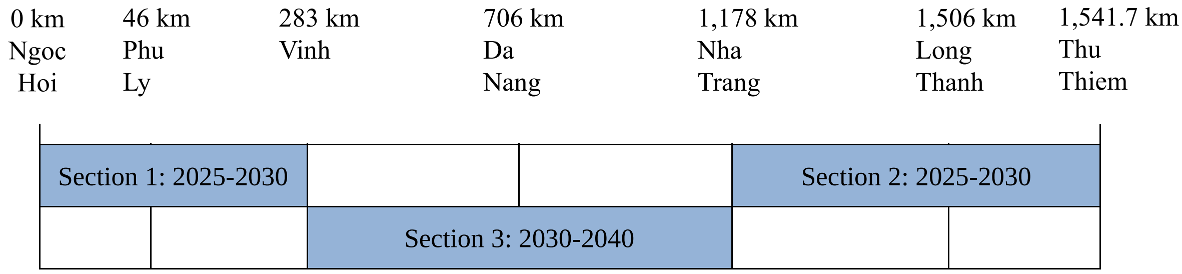
The permanent way shall be equipped with facilities corresponding to 320 km/h. The cant is set according to the maximum speed of 320 km/h. Therefore, excess of cant occurs when traveling at less than 320 km/h, which reduces the ride comfort. However, it is allowed as there is no problem in safety. The vehicles shall be adapted to 320 km/h operation so that they can be readily responded at the time of future speed up to 320 km/h.

(3) Construction Process

The construction process is the same as Case HSR (Two-step), assume a construction process divided into three sections over 2 stages. The operation period of the semi-high-speed rail runs until the opening of the middle section in 2040. The semi-high-speed rail will be operated in the northern and section in the first stage from 2030 to 2040.

The sections pertaining to the semi-high-speed are the Hanoi - Vinh 283 km in the northern section and the Nha Trang – Thu Thiem 363 km in the southern section, which will begin operation in 2030. In 2040, Vinh – Nha Trang 896 km will open and will shift from semi-high speed to high speed.

The construction process and overview are shown in the following figure and table.



Source: JICA Study Team

Figure 1.1: Construction Process (Case Semi HSR)

Table 1.1: Overview (Case Semi HSR)

Section	Origin and end station	Distance	Construction period	Opening	Max. operating speed
Section 1: North	Ngoc hoi – Vinh	283 km	2025-2030	2030	Until 2040: 200 km/h, After 2040: 320 km/h
Section 2: South	Nha Trang – Thu Thiem	363 km	2025-2030		
Section 3: Middle	Vinh – Nha Trang	896 km	2030-2040	2040	320 km/h

Source: JICA Study Team

2. Demand Analysis

2.1 Preconditions

The methodology of demand analysis for semi-high speed railway is the same as for High speed railway. Only the maximum speed of 200 km/h (average 150 km/h considering stopping at stations) differs from High speed railways. Fare level of semi-high speed railway is set as the same for HSR (900 VND/km). Where, sensitive analysis of fare variation (700 VND/km) would be tried since the level of service for travel time is low compared to HSR.

2.2 Results

Passenger volume between stations in 2030 is as follows compared with HSR. The volume for semi-high speed railway is approx. 13% less compared to HSR.

(1) North Section

Table 2.1: Comparison Passenger Volume between Stations (Year 2030) (North Section)

Semi HSR (200 km/h)	Ngoc Hoi	Phu Ly	Nam Dinh	Ninh Binh	Thanh Hoa	Vinh
Ngoc Hoi	0	10,796	11,715	1,529	3,115	4,654
Phu Ly	0	0	2	97	110	38
Nam Dinh	0	0	0	74	57	115
Ninh Binh	0	0	0	0	684	83
Thanh Hoa	0	0	0	0	0	1,796

HSR (320 km/h)	Ngoc Hoi	Phu Ly	Nam Dinh	Ninh Binh	Thanh Hoa	Vinh
Ngoc Hoi	0	11,034	12,070	1,603	3,337	8,676
Phu Ly	0	0	2	100	116	42
Nam Dinh	0	0	0	75	59	322
Ninh Binh	0	0	0	0	700	237
Thanh Hoa	0	0	0	0	0	2,139

Source: JICA Study Team, ( ) shows maximum speed

(2) South Section

Table 2.2: Comparison Passenger Volume between Stations (Year 2030) (South Section)

Semi HSR (200 km/h)	Thap Cham	Tuy Phong	Phan Thiet	Long Thanh	Thu Thiem
Nha Trang	1,008	578	866	893	8,039
Thap Cham	0	445	668	51	457
Tuy Phong	0	0	0	506	4,553
Phan Thiet	0	0	0	758	6,826
Long Thanh	0	0	0	0	12,415
Thu Thiem	0	0	0	0	0

HSR (300 km/h)	Thap Cham	Tuy Phong	Phan Thiet	Long Thanh	Thu Thiem
Nha Trang	1,231	589	884	1,386	12,470
Thap Cham	0	450	676	53	474
Tuy Phong	0	0	0	519	4,671
Phan Thiet	0	0	0	778	7,006
Long Thanh	0	0	0	0	12,415
Thu Thiem	0	0	0	0	0

Source: JICA Study Team, ( ) shows maximum speed

Source: JICA Study Team

Figure 2.1: Comparison Passenger Volume between Stations (Year 2030)

For reference, results of alternative case for fare level change is as follows. Passenger volume in case fare level would be set at 700 VND/km, which is the same as the existing railway, and close to that of HSR.

Table 2.3: Comparison Passenger Volume (Year 2030)

	Total passenger volume (Pax/day)			**Maximum section volume (Pax/day)**		
Fare level (VND/km)	900	800	700	900	800	700
Semi-HSR 200 km/h	72,928 (87)	76,537 (91)	80,341 (96)	32,290 (87)	34,662 (94)	37,692 (102)
HSR 320 km/h	84,114 (100)	-	-	37,036 (100)	-	-

Source: JICA Study Team, ( ) shows passenger volume index as of 100 for high-speed railway

3. Train Operation Plan

A train operation plan is considered for Case Semi HSR, in which the northern and southern sections are opened in 2030 at a maximum speed of 200 km/h, until 2040 when the whole line opens. After 2040, the train operation plan will be the same as Case HSR (Two-step) as the train speed increases to 320 km/h for the entire section.

3.1 Train Operation Plan (Case Semi HSR)

(1) Preconditions for Train Operation Planning

In formulating the operation plan, the following assumptions were made:

1) Operation starts in the northern section (Ngoc Hoi – Vinh) and the southern section (Nha Trang – Thu Thiem) by 2030.
2) The maximum train operating speed is 200 km/h.
3) The demand in this survey is the forecasted amount reflecting the train speed.
4) The vehicles are the same type as Case HSR (Two-step) for seamless transition to HSR in 2040.
   The train capacity is 555 for an 8-car train set, and the number of trains is almost the same as with Case HSR (Two-step).
   In high speed operation after 2040, 4 sets of electric motor car units (2 units) are connected to form 16-car trains.
5) The operating hours have been set to 6:00-24:00.

(2) Operating Time between Stations

No express trains are considered since the section length is short in the northern and southern sections. Table 3.1 and Table 3.2 show the inter-station distance and operating time calculated based on the above preconditions. The standing time at the station is 2 minutes. The time required between Ngoc Hoi – Vinh is 1 hours and 50 minutes, and 2 hours and 15 minutes between Nha Trang – Thu Thiem.

Table 3.1: Operating Time (Ngoc Hoi – Vinh)

Ngoc Hoi → Vinh

	Station Name	Center of Station (m)	Between Stations (m)	Operating Time	Standing Time (min)
				Ordinary Train	
1	Ngoc Hoi	0			
			46,300	16 : 30	
2	Phu Ly	46,300			2:00
			25,800	10 : 15	
3	Nam Dinh	72,100			2:00
			27,600	10 : 45	
4	Ninh Binh	99,700			2:00
			51,700	18 : 15	
5	Thanh Hoa	151,400			2:00
			131,100	42 : 15	
6	Vinh	282,500			
				1:38:00	8:00

Operating Time	1:38:00
Standing Time	8:00
Extra Time	0:04:00
Total	1:50:00

Vinh → Ngoc Hoi

	Station Name	Center of Station (m)	Between Stations (m)	Operating Time	Standing Time (min)
				Ordinary Train	
1	Vinh	0			
			131,100	42 : 15	
2	Thanh Hoa	131,100			2:00
			51,700	18 : 15	
3	Ninh Binh	182,800			2:00
			27,600	10 : 45	
4	Nam Dinh	210,400			2:00
			25,800	10 : 15	
5	Phu Ly	236,200			2:00
			46,300	16 : 30	
6	Ngoc Hoi	282,500			
				1:38:00	8:00

Operating Time	1:38:00
Standing Time	8:00
Extra Time	0:04:00
Total	1:50:00

Source: JICA Study Team

Table 3.2: Operating Time (Nha Trang – Thu Thiem)

Nha Trang → Thu Thiem

	Station Name	Center of Station (m)	Between Stations (m)	Operating Time Ordinary Train	Standing Time (min)
1	Nha Trang	0			
			76,900	25 : 45	
2	Thap Cham	76,900			2:00
			67,200	22 : 45	
3	Tuy Phong	144,100			2:00
			65,400	22 : 15	
4	Phan Thiet	209,500			2:00
			117,900	38 : 15	
5	Long Thanh	327,400			2:00
			36,000	13 : 15	
6	Thu Thiem	363,400			
				2:02:15	8:00

Operating Time	2:02:15
Standing Time	8:00
Extra Time	0:04:45
Total	2:15:00

Thu Thiem → Nha Trang

	Station Name	Center of Station (m)	Between Stations (m)	Operating Time Ordinary Train	Standing Time (min)
1	Thu Thiem	0			
			36,000	13 : 15	
2	Long Thanh	36,000			2:00
			117,900	38 : 15	
3	Phan Thiet	153,900			2:00
			65,400	22 : 15	
4	Tuy Phong	219,300			2:00
			67,200	22 : 45	
5	Thap Cham	286,500			2:00
			76,900	25 : 45	
6	Nha Trang	363,400			
				2:02:15	8:00

Operating Time	2:02:15
Standing Time	8:00
Extra Time	0:04:45
Total	2:15:00

Source: JICA Study Team

(3) Number of Trains by Section

The passenger volume between stations is shown in the table below.

Table 3.3: Passenger Volume between Stations (Case Semi HSR)

Passenger/Day/Round Trip

Section			2030
Ngoc Hoi	–	Phu Ly	31,809
Phu Ly	–	Nam Dinh	21,260
Nam Dinh	–	Ninh Binh	9,789
Ninh Binh	–	Thanh Hoa	8,856
Thanh Hoa	–	Vinh	6,686
Vinh	–	Ha Tinh	0
Ha Tinh	–	Vung Ang	0
Vung Ang	–	Dong Hoi	0
Dong Hoi	–	Dong Ha	0
Dong Ha	–	Hue	0
Hue	–	Da Nang	0
Da Nang	–	Tam Ky	0
Tam Ky	–	Quang Ngai	0
Quang Ngai	–	Phu My	0
Phu My	–	Dieu Tri	0
Dieu Tri	–	Tuy Hoa	0
Tuy Hoa	–	Nha Trang	0
Nha Trang	–	Thap Cham	11,384
Thap Cham	–	Tuy Phong	11,997
Tuy Phong	–	Phan Thiet	16,033
Phan Thiet	–	Long Thanh	22,083
Long Thanh	–	Thu Thiem	32,290

Source: JICA Study Team

The number of trains is set so that the average boarding ratio is assumed at 70% which is the same as Case HSR (Two-step).

Table 3.4: Number of Trains by Section (Case Semi HSR)

		Passenger Volume	Train Set		Number of Trains			Section Length	Train-km
			Number of Cars	Passenger Capacity	Number of Passengers	Culculated Number of Train	Setting Number of Train		
		A	B	C	D = C×0.7	= A /(2× D)	F	G	H = F× 2 ×G
NGOC HOI	− VINH	31,809	8	555	388.5	40.9	42	282.5	23,730.0
VINH	− DA NANG								
DA NANG	− NHA TRANG								
NHA TRANG	− THU THIEM	32,290	8	555	388.5	41.6	42	363.4	30,525.6

A Maximum Passenger Volume by Section (Person/Day/Round-Trip)

B Number of Cars (Cars/Train)

C Passenger Capacity of Train (Passenger/Train)

D Number of Passengers when load factor is 70% (Passenger/Train)

E Culculated number of Trains (Number of Trains/Day/One-way)

F Setting Number of Trains with consideration of Operation of Train Sets (Number of Trains/Day/One-way)

G Section Length (km)

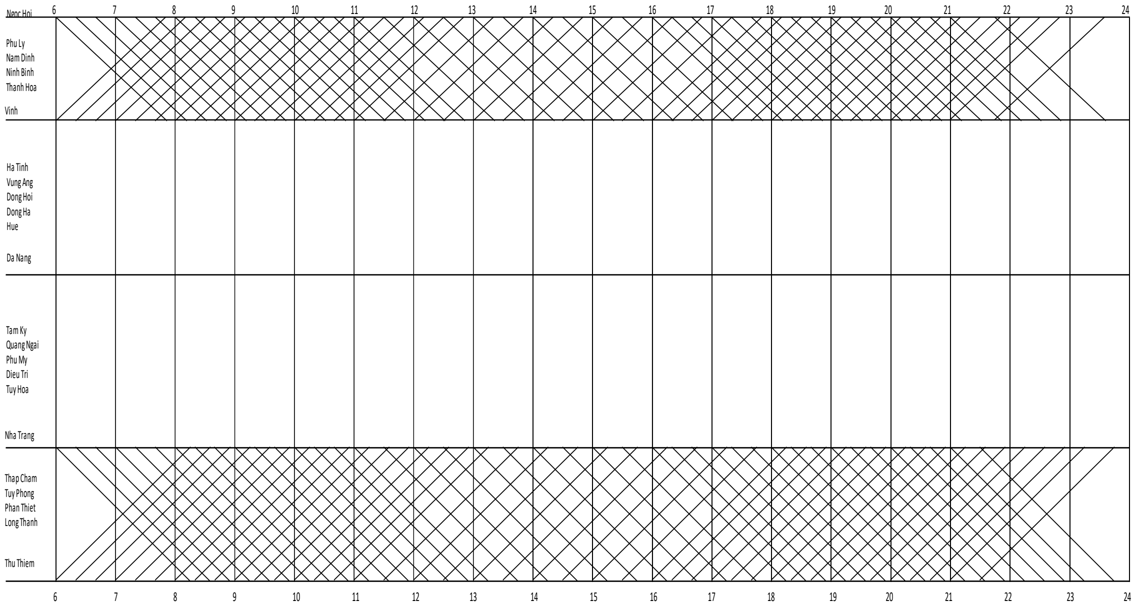
H Train-km excluding Deadheading operation between Stations and Depots (km/Day/Round-Trip)

Source: JICA Study Team

(4) Train Schedule and Required Train Sets

Both for the northern (Ngoc Hoi – Vinh) and southern (Nha Trang – Thu Thiem) sections, 2 trains per hour/one-way have been set, but in the morning and evening rush hours, 3 trains per hour/one-way are considered.

The next figure shows the train schedule, and the next table indicates the number of train sets required by depot.



Source: JICA Study Team

Figure 3.1: Train Diagram in 2030 (Case Semi HSR)

Table 3.5: Number of Train Sets per Depot (Case Semi HSR)

8Carriages (6M2T)

Depot	Local Train	Sub-Total	Sub-Total×0.1	Reserve Train	Total
Ngoc Hoi	8	8	0.8	1	9
Vinh	8	8	0.8	1	9
Da Nang	0	0	0	0	0
Nha Trang	9	9	0.9	1	10
Thu Thiem	9	9	0.9	1	10
Total	34	34	3.4	4	38

The table does not include train sets for inspections.

At least one reserve train is deployed at each depot.

Source: JICA Study Team

3.2 Comparison with High Speed Operation

The following compares semi-high speed operation with HSR.

(1) Operating Time

Table 3.6 and Table 3.7 show the comparison of operating time between high speed operation (Case HSR) and semi-high-speed operation (Case Semi HSR). In the northern section (Ngoc Hoi

– Vinh), semi-high speed rail requires 110 minutes, around 30 minutes longer than HSR at 82 minutes. In the southern section (Nha Trang – Thu Thiem), semi-high speed takes 135 minutes, around 40 minutes longer the 90 minutes for HSR.

Table 3.6: Time Comparison in the Northern Section (Ngoc Hoi – Vinh)

Ngoc Hoi → Vinh

	Station Name	Operating Time		Standing Time (min)
		HSR	Semi-HSR	
1	Ngoc Hoi			
		12 : 00	16 : 30	
2	Phu Ly			2:00
		8 : 15	10 : 15	
3	Nam Dinh			2:00
		8 : 30	10 : 45	
4	Ninh Binh			2:00
		13 : 00	18 : 15	
5	Thanh Hoa			2:00
		28 : 00	42 : 15	
6	Vinh			
		1:09:45	1:38:00	8:00

Operating Time	1:09:45	1:38:00
Standing Time	8:00	8:00
Extra Time	0:04:00	0:04:00
Total	1:21:45	1:50:00

Vinh → Ngoc Hoi

	Station Name	Operating Time		Standing Time (min)
		HSR	Semi-HSR	
1	Vinh			
		28 : 00	42 : 15	
2	Thanh Hoa			2:00
		13 : 00	18 : 15	
3	Ninh Binh			2:00
		8 : 30	10 : 45	
4	Nam Dinh			2:00
		8 : 15	10 : 15	
5	Phu Ly			2:00
		12 : 00	16 : 30	
6	Ngoc Hoi			
			1:38:00	8:00

Operating Time	1:09:45	1:38:00
Standing Time	8:00	8:00
Extra Time	0:04:00	0:04:00
Total	1:21:45	1:50:00

Source: JICA Study Team

Table 3.7: Time Comparison in the Southern Section (Nha Trang – Thu Thiem)

Nha Trang → Thu Thiem

	Station Name	Operating Time		Standing Time (min)
		HSR	Semi-HSR	
1	Nha Trang			
		17:45	25 : 45	
2	Thap Cham			2:00
		16 : 00	22 : 45	
3	Tuy Phong			2:00
		15 : 45	22 : 15	
4	Phan Thiet			2:00
		25 : 30	38 : 15	
5	Long Thanh			2:00
		10 : 00	13 : 15	
6	Thu Thiem			
		1:25:00	2:02:15	8:00

Operating Time	1:25:00	2:02:15
Standing Time	8:00	8:00
Extra Time	0:04:45	0:04:45
Total	1:37:45	2:15:00

Thu Thiem → Nha Trang

	Station Name	Operating Time		Standing Time (min)
		HSR	Semi-HSR	
1	Thu Thiem			
		10 : 00	13 : 15	
2	Long Thanh			2:00
		25 : 30	38 : 15	
3	Phan Thiet			2:00
		15 : 45	22 : 15	
4	Tuy Phong			2:00
		16 : 00	22 : 45	
5	Thap Cham			2:00
		17 : 45	25 : 45	
6	Nha Trang			
		1:25:00	2:02:15	8:00

Operating Time	1:25:00	1:38:00
Standing Time	8:00	8:00
Extra Time	0:04:45	0:04:00
Total	1:37:45	1:50:00

Source: JICA Study Team

(2) Transport Volume and Number of Trains

Table 3.8 and Table 3.9 show the comparison of the transport volume between stations and the number of train sets.

Table 3.8: Comparison of Transport Volume between Stations

Passenger/Day/Round Trip

Section			HSR	Semi-HSR
Ngoc Hoi	–	Phu Ly	36,720	31,809
Phu Ly	–	Nam Dinh	25,946	21,260
Nam Dinh	–	Ninh Binh	14,330	9,789
Ninh Binh	–	Thanh Hoa	13,489	8,856
Thanh Hoa	–	Vinh	11,416	6,686
Nha Trang	–	Thap Cham	16,560	11,384
Thap Cham	–	Tuy Phong	16,982	11,997
Tuy Phong	–	Phan Thiet	21,133	16,033
Phan Thiet	–	Long Thanh	27,357	22,083
Long Thanh	–	Thu Thiem	37,036	32,290

Source: JICA Study Team

Table 3.9: Comparison of the Number of Trains

	Section	Passenger Volume	Train Set		Number of Tran			Section Length	Train-km
			Number of Car	Passenger Capacity	Number of Passenger	Number of Train	Setting Number of Train		
		A	B	C	D = C×0.7	= A/(2× D)	F	G	H = F×2×G
Case HSR (Two-step)	Ngoc Hoi – Vinh	36,720	10	740	518	35.4	36	282.5	20,340.0
	Nha Trang – Thu Thiem	37,036	10	740	518	35.7	36	363.4	26,164.8
Case Semi HSR	Ngoc Hoi – Vinh	31,809	8	555	388.5	40.9	42	282.5	23,730.0
	Nha Trang – Thu Thiem	32,290	8	555	388.5	41.6	42	363.4	30,525.6

A Maximum Passenger Volume by Section (Person/Day/Round-Trip)

B Number of Cars (Cars/Train)

C Passenger Capacity of Train (Passenger/Train)

D Number of Passengers when load factor is 70% (Passenger/Train)

E Culculated number of Trains (Number of Trains/Day/One-way)

F Setting Number of Trains with consideration of Operation of Train Sets (Number of Trains/Day/One-way)

G Section Length (km)

H Train-km excluding Deadheading operation between Stations and Depots (km/Day/Round-Trip)

Source: JICA Study Team

(3) Required Train Sets

Table 3.10 shows the comparison for the number of train sets per depot. The number of train sets for Case Semi HSR is 38, more than 30 for Case HSR; and the number of cars for Case Semi HSR is 304, 4 more cars than Case HSR. This indicates that low speed operation requires more cars caused by the lower efficiency of transportation, despite a decline in demand.

Table 3.10: Number of Train Sets for Operation

2030	Case HSR (10 cars)			Case Semi HSR (8 cars)		
	Operation	Reserve	Total	Operation	Reserve	Total
Ngoc Hoi	6	1	7	8	1	9
Vinh	6	1	7	8	1	9
Nha Trang	7	1	8	9	1	10
Thu Thiem	7	1	8	9	1	10
Total (Train-set)	26	4	30	34	4	38
Total number of cars			300			304

Noted that the table does not include train sets for inspections. At least one reserve train is deployed at each depot.
Source: JICA Study Team

4. Railway Facilities

The premise here is to open the semi-high-speed operation in 2030 and to increase the speed to 320 km/h in 2040. Therefore, the ground facilities of Case Semi HSR are the same as Case HSR (Two-step), which starts at high speed from the beginning. Because the renewal in 10 years is not realistic in terms of service life and replacement cost, the difference in facilities between semi-high speed and high speed is limited to vehicles.

4.1 Rolling Stock

(1) Number of Train Sets Including Inspection

To maintain the rolling stock, daily inspections, regular inspections, bogie inspections, and general inspections are required. The inspection cycle is determined according to the running distance and the number of days traveled. Since rolling stock cannot be used for passenger service during the above-mentioned inspection period at a depot, it is necessary to prepare extra train sets for this purpose.

The following table compares the number of train sets and the number of cars both for Case HSR and Case Semi HSR, including for inspection

Table 4.1: Comparison of Number of Train Sets Including Inspection Use (2030)

Item	Case HSR		Case Semi HSR		Note
	Hanoi – Vinh	Nha Trang – Thu Thiem	Hanoi – Vinh	Nha Trang – Thu Thiem	
Distance	282.5	363.4	282.5	363.4	km
Number of trains	72	72	84	84	/day /round trip
Train set for service	12	14	16	18	
Train set for reserve	2	2	2	2	
Train set for operation	14	16	18	20	
Train-km	20,376	26,136	23,730	30,526	/day
Train-km	1,455	1,634	1,318	1,526	/day /set
Regular inspection cycle (day)	21	18	23	20	30,000 km or 30 days
Bogie inspection cycle (day)	412	367	455	393	60,000 km or 1.5 years
General inspection cycle (day)	824	735	910	786	120,000 km or 3 years
Train set for regular inspection	1	1	1	1	train set
Train set for Bogie inspection	1	1	1	1	train set
Train set for general inspection	1	1	1	1	train set
Train set for inspection	3	3	3	3	train set
Total train set for section	17	19	21	23	train set
Number of train sets		36		44	train set
Number of cars		360		352	car

Source: JICA Study Team

(2) The Purchase Price of Rolling Stock

The purchase price of the rolling stock is as follows

Table 4.2: Comparison of Rolling Stock Cost

2030	Case HSR	Case Semi HSR
Number of cars (cars/train)	10	8
Number of train sets (train set)	36	44
Number of cars (car)	360	352
Purchase cost (mil. USD)	Removed	

Source: JICA Study Team

4.2 Investment Cost

This item has been removed because of confidential information.

5. Operation and Maintenance

(1) Organization and Employees

The organizational structure of Case Semi HSR is assumed to be the same as Case HSR. The number of employees is assumed considering the work volume. It is considered that the work volume doesn't change compared to Case HSR for the headquarters, branch offices, stations, railway maintenance, electrical circuit maintenance, and procurement of materials. On the other hand, the work time of the drivers and conductors increases as the speed goes down. As the mileage of rolling stock reduces, the number of repair personnel decreases. The next table shows the comparison of employees between Case HSR and Case Semi HSR.

Table 5.1: Comparison of Employees (2030)

Organization		Number	Case HSR	Case Semi A	Difference
Head office		1	173	173	
Hanoi Branch Office	Main Branch office	1	194	194	
	Station	6	357	357	-
	Driver/ Conductor Depot	2	131	210	79
	Rolling stock Inspection Base	1	38	28	-10
	Rolling Stock Workshop	1	318	239	-79
	Track maintenance-depot	3	429	429	
	Power Supply Station-depot	3	337	337	
	Signaling/Telecommunications-depot	3	284	284	
	Material Center	2	50	50	
	Total	22	2,138	2,128	10
HCMC Branch Office	Main Branch office	1	194	194	
	Station	6	371	371	
	Driver/ Conductor Depot	2	156	258	102
	Rolling stock Inspection Base	1	38	37	-1
	Rolling Stock Workshop	1	318	307	-11
	Track maintenance-depot	3	595	595	
	Power Supply Station-depot	3	435	435	
	Signaling/Telecommunications-depot	3	362	362	
	Material Center	2	50	50	
	Total	22	2,519	2,609	90
Whole company	Head office	1	173	173	
	Main Branch office	2	388	388	
	Station	12	728	728	
	Driver/ Conductor Depot	4	287	468	181
	Rolling stock Inspection Base	2	76	65	-11
	Rolling Stock Workshop	2	636	546	-90
	Track maintenance-depot	6	1,024	1,024	
	Power Supply Station-depot	6	772	772	
	Signaling/Telecommunications-depot	6	646	646	
	Material Center	4	100	100	
	Total	45	4,830	4,910	80

Source: JICA Study Team

(2) Labor Cost

This item has been removed because of confidential information.

(3) Power Consumption

The amount of electricity consumed by a train varies depending on the speed and mileage. Case HSR considers the power consumption of a 10-car train runs at a speed of 320 km/h as 31.7

kwh/train/km. The power consumption of Case Semi HSR of an 8-car train at a speed of 200 km is 18.1 kwh/train/km. This value is derived as follows:

The following empirical formula[1] shows the relationship between the speed of the Shinkansen and running resistance.

$$R = 1.60 + 0.0350\,V + (0.0197 + 0.00241 \cdot n) \cdot V^2/W$$

Where;

R: Running resistance (kgf)
V: Train Speed (km/h)
W: Train Weight (ton)   500 ton/10cars

According to the above equation, the running resistance at 320 km/h (10-car train) and 200 km/h (8 car train) is as follows.

320 km/h (10 cars):   21.8 kgf
200 km/h (8 cars):   12.5 kgf

Assuming power consumption is proportional to running resistance, Case Semi HSR consumes 57% (= 12.5/21.8) of Case HSR. Therefore, Case Semi HSR consumes 18.1 kwh/train/km (= 31.7 * 0.57).

The following table compares the annual electric energy for train operation between Case HSR and Case Semi HSR.

Table 5.2: Comparison of Electric Energy for Operation

Item	Case HSR	Case Semi HSR
Mileage (train-km/day)	46,505	54,256
Power consumption (kwh/train-km)	31.7	18.1
Annual Electric Energy (mill. kwh/year)	538	360

Source: JICA Study Team

Usually, stations and factories use 10% of the electric energy for operation. Considering the additional electricity and multiplying the expected unit charge, the following table depicts the total calculated power costs.

Table 5.3: Energy Consumption and Power Cost

Item	Case HSR	Case Semi HSR
Power for operation (mil. kwh/year)	538	360
Power for others (mil. kwh/year)	54	36
Total power (mil. kwh/year)	592	396
Power cost (mil. USD)	Removed	

Source: JICA Study Team

(4) Maintenance of Vehicles

Vehicle maintenance cost (excluding personnel expenses) is made up of parts and material costs, overhead expenses, and vehicle washing expenses. The parts and material costs and overhead expenses are assumed to be 1.5% and 0.3% of owned vehicle price, respectively. The following table shows the comparison of maintenance costs between Case HSR and Case Semi HSR.

[1] JNR Operation Department

Table 5.4: Maintenance Costs of Rolling Stock

Item	Case HSR			Case Semi HSR		
	North	South	Total	North	South	Total
Number of cars (car)	170	190	360	168	184	352
Price of owned vehicle (mil. USD)	[redacted]					
Parts and material cost (mil. USD)						
Overhead expenses (mil. USD)	Removed					
Vehicle cleaning cost (mil. USD)						
Total (mil. USD)						

Source: JICA Study Team

(5) Comparison of Non-personnel Expenses

This item has been removed because of confidential information.

(6) Summary of Operation and Management Costs

This item has been removed because of confidential information.

6. Preliminary Economic Evaluation of Semi-high Speed Case

This chapter has been removed because of confidential information.